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Minister of Fisheries

Some Water Pollution Problems Connected with the Disposal of Pulp Mill Wastes

by

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Introduction

Of the eleven major pulp and paper mills producing in British Columbia, ten are located on tide water. There are five mills on Vancouver Island alone (Figure 1). The economy of British Columbia is dependent to a large extent on its forest resources and there is no doubt that the number of pulp mills will increase rapidly in the future as new demands develop for pulp and paper. There are known to be at least two pulp mills on the planning boards for the British Columbia coast which are only awaiting a more attractive market for pulp before they start actual construction. Plans for two new pulp mills to be established in the interior of the province, on the Fraser River near Prince George, were announced early in 1962.

Most of the pulp mills in British Columbia are located on the coast because of several features which are favourable for pulp production. The heavy timber is located on the seaward slopes of the coastal mountains. Available streams provide abundant, fresh water for pulp and paper manufacture as well as cheap hydroelectric power. Deep harbours adjacent to most of these pulp mills allow installation of suitable deep-sea shipping facilities for reaching world markets. They make available also cheap transport of raw materials by chip scows and large log booms brought in from other parts of the coast.

A conflict arises in the development of pulp mills along the coast, because some of the features that are desirable for the pulp industry are also important to anadromous fishes. Fresh water from the streams is diverted for use in pulp mill processes. The contaminated water is then ejected either into the stream or into the nearby sea. Salmon must pass through heavily polluted waters in both their seaward migration as juveniles and in their spawning migration as adults.

Authorities in some areas have become cognizant of the threat of pulp mill wastes to water quality so that comprehensive investigations have been made well in advance of pulp mill developments (California State Water Pollution Control Board, 1957; Canada Department of Fisheries *et al.*, 1961).

Properties of pulp mill wastes, particularly with respect to water pollution

The total effluent from a pulp mill consists of liquid wastes from the various mill processes, washings from plant operations and general plant sewage. It is largely fresh



FIGURE 1. Chart of the British Columbia coast showing locations of existing and projected pulp mills.

water contaminated in varying degrees by dissolved and particulate wood products, as well as by chemicals lost from the digestion and bleach processes.

Pulp mill wastes may be classified into two basic categories, as arising from (a) chemical digestion and (b) mechanical pulping. A semi-chemical pulp is also produced in small quantities by light chemical digestion followed by mechanical disintegration. The spent liquor from chemical digestion contains the salts used in the "cooking" process, as well as the organic materials binding the cellulose fibres in the wood that have been dissolved during digestion. Mechanical pulping consists of the grinding of wood blocks on stone wheels in the presence of water. Effluent from this process contains only a small amount of dissolved organic substances leached from the wood and a considerable amount of small fibres.

Chemical digestion is further sub-divided into two basic types: (1) acidic (sulphite) process, where a solution of sulphurous acid combined with calcium, magnesium or other base is used for cooking the wood; and (2) alkaline (sulphate) process where a solution consisting mainly of sodium hydroxide and sodium sulphide is used.

The chemical characteristics of wastes are quite different from one chemical process to another. There are a number of physical properties, however, which are generally common to most wastes from all chemical pulping.

Some of the constituents dissolved from wood give effluents from chemical processing of pulp certain surface-active properties. The tendency to foam is a direct result of low surface tension of the effluent (Figures 2 and 3). Although foam itself is not especially harmful to organisms, it impairs the aesthetic qualities of surface waters. Its affinity for particulate materials in the effluent and other foreign matter on the water surface contributes to small accumulations of undesirable materials along the shores. This may have some adverse effects on oysters and other fauna in the marine intertidal zone.

Aside from foaming characteristics, the rate with which water can be re-oxygenated is dependent on the amount of surface-active material present in the water. Large quantities of detergents are known to reduce the rate and amount of oxygen uptake by sewage treatment plant effluents. It is probable that the same effect prevails in the uptake of oxygen by waters containing large amounts of effluent from chemical pulping.



FIGURE 2. A field of foam collected within a log-boom enclosure at the outfall discharging effluent from a full-bleach kraft pulp mill near Nanaimo (Harmac).



FIGURE 3. Discharge of foamy wastes from the bleach-plant sewer of the sulphite pulp mill on Watson Island, adjacent to Port Edward.

Density of effluent is variable from mill to mill and may vary over a period of time in the same mill, depending on the amounts of dissolved salts and organic materials which are wasted. In general, it is only slightly heavier than natural fresh water but considerably lighter than sea water. The surface-active properties of pulp mill effluents ensure that they will disperse rapidly if they are injected into water having approximately their density. Consequently, it can be expected that the effluent will mix freely with fresh water but will tend to spread on the surface of sea water. Under the normal condition of stratification, with light water at the surface and denser water below in the coastal marine environment, the effluent tends to mix only in the upper brackish layer if it is discharged at the sea surface.

(a) Sulphite Pulp Wastes

There is very little recovery practised in the sulphite process, except in some of the modern mills where a recoverable base (magnesium, ammonia, or sodium) is used. Spent sulphite liquor (SSL) is an amber-coloured fluid rich in organic substances. It is noted mainly for its oxygen-consuming qualities. On a population equivalent basis, the oxygen consumption of effluent from a 500-ton-per-day sulphite mill may be equivalent to that of sewage from two million persons. The high concentration of wood sugars in SSL results in rapid decomposition by bacteria and, consequently, a high B.O.D. (biochemical oxygen

demand). There are numerous other organic constituents, of which lignin is the most significant, but they are generally more resistant to bacterial attack. These compounds are comparatively non-toxic, except for perhaps methyl alcohol, formic acid and furfural, which are present only in small concentrations.

Depending on the grade of sulphite pulp produced, the amount of wood substance discharged as waste can vary from 55 to 63 per cent of the raw material. When the spent chemicals released in the waste are also taken into consideration, there is a total solids discharge per ton of pulp (dry weight) which varies from about 3000 lb to 4000 lb.

Unused sulphur dioxide, present in wastes in the form of sulphurous acid, can be toxic to fish. It can be responsible also for the lowering of dissolved oxygen concentration in receiving waters by its powers of chemical reduction. Sulphurous acid may be the principal contributor to the immediate oxygen demand (I.O.D.) which amounts to approximately 10 per cent of the total 5-day B.O.D.

(b) Kraft Pulp Wastes

Alkaline digestion of wood chips, popularly referred to as the "kraft" process because of the high strength of the fibres produced, is now the principal method of pulp production in British Columbia. Recovery of the spent cooking solution ("black liquor") from the digestion is practised as an integral part of the kraft process, by which certain economies in heat and salt recovery are realized. Kraft mill effluent (KME) usually consists of washings from the various screening and bleaching processes that cannot be recirculated, dregs from the causticizing plant, condensates, floor drainage, other unusable residues and sanitary sewage. Because sodium sulphide is used in the cooking liquor, certain toxic sulphur-containing compounds emerge with the black liquor. Hydrogen sulphide and mercaptans are the most noteworthy components of this group, and they are generally responsible for the notoriety of kraft pulp mills in atmospheric pollution. In addition to the sulphur compounds, KME also contains tall oil, resin and fatty acid soaps derived from the black liquor and usually separated in the recovery plant. While the sulphides and mercaptans are quite unstable and seldom occur in dangerous concentrations beyond the sewer outfall, the resin and fatty acid soaps are relatively stable and may be the major contributors to the toxicity of kraft pulp mill wastes.

The B.O.D. of kraft mill effluent is comparatively low, being about one-tenth of that of spent sulphite liquor. However, it is significant enough so that in some of our marine situations it limits the amount of KME that can be safely discharged. The deep brown colour often associated with kraft mill effluent is characteristic of the form of lignin released by the kraft process. It does not represent a particularly toxic condition nor one of high B.O.D. but only the presence of a coloured material which happens to be a fairly sensitive tracer for the waste.

(c) Bleach Plant Wastes

Bleach plant effluent is one of the less harmful components of pulp mill sewage. There is, however, a certain amount of B.O.D. associated with bleach effluent which may be as high as that of KME. The first bleaching stage in a kraft pulp mill consists of chlorination followed by a caustic extraction, wherein the dark-coloured constituents attached to the fibres form chlorinated lignin and are removed by dissolving with sodium hydroxide solution. Effluent from this stage is not recirculated but wasted to the sewer. Most of the

dark brown pollution characteristics of a full-bleach kraft pulp mill originate from this operation. Presence in the wastes of residual calcium hypochlorite, chlorine and chlorine dioxide used in the other bleaching stages can actually benefit the oxidation processes acting on the organic materials present in the mill wastes. It is usually recommended that bleach plant wastes be mixed with the other mill wastes before release into the sea. An added advantage in admixture of spent zinc hydrosulphite bleach solution, where bleaching of groundwood for newsprint is practised using this chemical, is that foaming of the total mill effluent can be appreciably reduced (Figure 4).

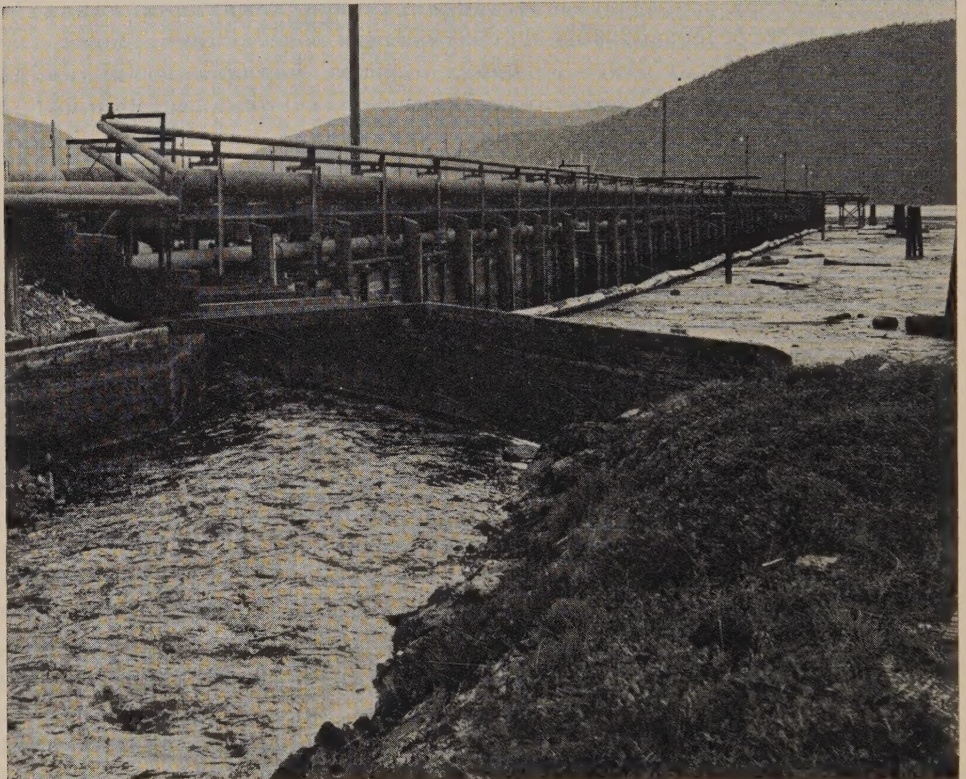


FIGURE 4. Discharge of total combined wastes from the kraft pulp and newsprint mill at Port Alberni into the surface waters of Alberni Inlet, by way of a flume.

(d) *Groundwood, Woodroom and Paper-machine Wastes*

Wastes from mechanical pulping and other non-chemical wood processing are harmful to the marine environment, mainly by virtue of the high concentrations of suspended particulate materials. Groundwood, produced by mechanical grinding, is used mainly in the production of newsprint. Addition of kraft or sulphite pulp provides the longer fibres to give the paper strength. Some of the groundwood pulp is lost to the sewer in various stages of processing and in formation of paper. There is a nominal B.O.D. associated with groundwood wastes arising from decomposition of raw organic constituents leached from the wood. This is considered only incidental when the groundwood mill is part of a much larger chemical-pulp plant.

Woodroom operations, such as hydraulic or mechanical barking and sawing, yield effluents that are sometimes highly discoloured from the bark extracts and contain a great deal of particulate material in the form of bark fragments, knots, wood chips and slivers. Effluents from woodrooms of most mills are at least coarse-screened before being released. However, there are still large amounts of particulate materials settling out in fresh waters as well as in the sea adjacent to pulp mills. While dissolved chemical constituents are mainly responsible for the acute effects of toxic and low-oxygen conditions, the accumulation of particulate materials often leads to harmful long-term effects (Figures 5A and 5B).

Effluent from paper-machine operations has a characteristic milky appearance and is commonly referred to as "white water" in the parlance of the pulp and paper trade. White water consists of a suspension of fine fibres, essentially in colloidal form. In the production of specialty printing papers, where clay or other sizing materials are used to give the paper gloss, the amount of colloidal material is often increased. Discharged into fresh water, such effluents disperse by dilution without appreciable settling of particulate, colloidal materials. The flocculating effect of sea water tends to precipitate the solid constituents when the wastes are released into the marine environment.

Comparison of effects of disposal of pulp mill wastes in fresh water and in sea water

To give this paper a little broader appeal, particularly for freshwater workers, the effects of waste disposal in sea water are compared with those in fresh water. Most research on pulp mill pollution in the past has been done on streams. The National Council for Stream Improvement in the United States has sponsored a great deal of research throughout the northern states on the effects of various pulp mill wastes in streams. Some of the results of this work are summarized along with a review of other researches by Gehm (1953). A fine piece of investigation was carried out on the effect of pulp mill pollution on the Spanish River in Ontario under the auspices of the Ontario Department of Lands and Forests (Dymond and Delaporte, 1952). Work in the American Pacific Northwest states of Washington and Oregon has been carried out primarily on streams, although estuarine pollution has received a certain amount of attention. The perennial pulp mill pollution problem in Washington concerns the effect of spent sulphite liquors in Puget Sound on the Olympia oyster, *Ostrea lurida* (Gunter and McKee, 1960).

The basic effects of pulp mill pollution on the aquatic environment are the same in both fresh water and in the sea, namely:

- (1) dissolved oxygen in the water is reduced to low concentrations by the decomposition of organic substances in the waste;
- (2) the toxic constituents of pulp mill waste, particularly those in kraft mill effluent, are known to be harmful to fish;
- (3) the particulate materials present in pulp mill effluents deposit on the bottom and modify the environment adversely for both bottom invertebrates and for any types of bottom fish present.

The basic differences of the effect of pulp mill pollution on the two environments stem from the salt content of sea water. Water of higher salinity has a higher density. Water of high salt concentration settles to the bottom while fresh water floats at the surface. This contributes to horizontal lamination where there are layers of water increasing



FIGURES 5A and 5B. A field of fibres and other particulate materials from sulphite wastes settled out in a natural lagoon adjacent to the sulphite pulp mill near Port Edward, showing a pole being inserted (5A) and withdrawn (5B) from the sludge bed.

in salt concentration with depth. Density stratification reduces the possibility of seasonal turnover of the water. Thus exchange of bottom water in stratified marine areas is much slower than that in fresh waters.

The presence of weak-acid salts in sea water, such as carbonates, borates and silicates, gives a higher buffering capacity in the marine environment than is available in fresh water. Strongly alkaline or acidic wastes are rapidly brought to the slightly alkaline conditions around a pH of 8, prevailing in sea water, as mixing and dilution in the sea take place.

Sea water acts as a strong electrolyte owing to the presence of highly-ionized salts, mainly sodium chloride. Consequently, it is a good conductor for an electric current, and this property is used in applications of various instruments, including devices for measuring salinity. The electrically-charged ions in saline solutions can also serve a function in the reaction of sea water with natural and artificially-introduced suspended materials. Silt-laden fresh waters, the Fraser River for example, are colloidal suspensions of very fine silica and clay particles. When these negatively-charged micelles of clay come into contact with positively-charged ions in sea water, there is neutralization of charge and the particles coalesce. Thus flocculation of the silt takes place near the Fraser River estuary and a large deposition of heavier-than-water silt aggregates occurs daily at the river delta. In a similar way, although little is known quantitatively about it, the fibres present in pulp mill effluent are precipitated out in the sea by the flocculating effect of sea water.

While salts in water contribute to its "hardness" and prevent foaming of soaps and detergents, they appear to have little effect as an anti-foam agent with pulp mill effluent. Sea water, in fact, appears to enhance the frothing action of some of the black-liquor constituents of kraft mill effluent (Figure 2). The so-called "red water" as well as bleach plant wastes from sulphite pulp production have a strong tendency to foam (Figure 3). The presence of sulphite wastes in the sea can be identified many miles from its source as a result of foam stirred up by wind mixing or even in the wake of a ship. Near Prince Rupert, the sea water contaminated by spent sulphite liquor produces great quantities of foam each time it surges through Zanardi Rapids with a strong, turbulent tidal current (Figure 10).

As a nutrient-rich source, sea water provides an ideal medium in which pulp mill wastes can decompose under the action of bacteria. Although terrestrial bacteria are rapidly destroyed by the properties which are unfavourable for their growth in the sea, marine bacteria are quite numerous and act in a way similar to land micro-organisms toward destruction of organic matter. In contrast to fresh water, however, sea water does not actively support the growth of some of the unsightly slime fungi. *Sphaerotilus* appears to be strictly a freshwater problem. Certain scum-like materials having a greyish-white appearance have been seen in sea water near sulphite pulp mills, especially at Port Alice, British Columbia (Waldichuk, 1958). Substances similar to these have been identified as *Leptomitus* in Bellingham Bay, which receives sulphite wastes from a mill at Bellingham, Washington (R. A. Wagner, personal communication).

The usually fertile conditions in coastal sea water provide a favourable environment for plant and animal life. Generally, the numbers of species and individuals of a particular species are much greater in the sea than in fresh water. However, there is the same delicate balance of organisms within the biological community and with the environment both in the sea and in fresh water.

Table I

Comparison of the characteristics of the freshwater and marine environments with respect to disposal of pulp mill wastes.

Property or process	Fresh water	Coastal Sea water
Salt content	Low	High 20 to 35‰ (2.0 to 3.5%)
Horizontal stratification	Small	Large
Vertical stability	Low	High
Seasonal overturn	Occurs usually in autumn, when surface water reaches temperature of 4°C and its maximum density. Replacement of bottom water allows a regular replenishment of dissolved oxygen.	Seldom occurs if there is fresh water at the surface, because of dominant effect of salinity on density. Usually remains stratified with bottom water essentially stagnant and slow replenishment of dissolved oxygen therein.
Dissolved oxygen replenishment		
Buffering capacity	Low, unless weak-acid salts present.	High, due to carbonates, borates and other weak-acid salts.
Flocculating action	Poor, unless flocculating agents present. (Presence of brown "humic acids" may actually assist in dispersion.)	High, due to presence of strong electrolytes.
Bacteriacidal and fungicidal action	Not generally present. (<i>Sphaerotilus</i> usually develops when sulphite wastes added.)	High. Various marine properties and processes lead to destruction of terrestrial bacteria and freshwater fungi.
Dilution and dispersion	Currents, due to gravitational force, provide principal mixing and transporting mechanism in streams.	Tides, runoff and winds generate mixing and transporting processes.
Self-purification	Turbulence, aeration and algal growth in a stream usually lead to self-purification of the water.	Processes in the sea are generally less effective than those in fresh water for effecting self-purification of the water.
Aquatic organisms	Depending on fertility of water, amount of aquatic life may be low or quite high.	Dense flora and fauna in marine waters, especially along the coast, in nutrient-rich sea waters.
Silt content and presence of other particulate materials.	Varies from stream to stream. Generally high silt content in B. C. streams.	Comparatively low in silt along B. C. coast, except at river estuaries. Probably higher concentration of organic detrital materials than in fresh water.
Foaming properties	Soft-water stream or lake has marked foaming properties; foam forms when surface-active agents, such as detergents and sulphite pulp mill wastes, are introduced in the presence of turbulence.	Salinity generally suppresses foaming tendency of soaps and detergents. High concentrations of spent sulphite liquor and kraft mill effluent in sea water cause foaming as high or higher than in fresh water.

While the oceans contain infinitely more water than lakes and streams, the amount of water available for dilution and dispersion in the sea may be severely restricted by certain characteristics of the marine environment. The matter of stratification has already been mentioned with respect to the nearshore marine environment, where there is considerable influence from freshwater runoff. Water movements in the sea are not always such that dispersion is invariably provided. There are exposed coastal areas where wastes released into the surf zone tend to be constrained in a narrow band along the coast because of onshore winds and alongshore currents (T. F. W. Harris, personal communication). In contrast, there is a continuous flow of water in a river toward its estuary so that a steady replacement of fresh water occurs in the area of input of pollutant. Reaeration contributes to the well-known phenomenon of self-purification in freshwater streams. Similar processes occur in marine inlets where runoff contributes to a strong seaward flow at the surface, but reaeration is probably not as significant as in turbulent rivers.

A tabulated comparison of the characteristics of fresh and sea waters with respect to disposal of pulp mill wastes is given in Table I.

Forces affecting dilution and dispersion of wastes in the sea

The objective in effective waste disposal into any environment is dilution to low concentrations and dispersion away from the source of the waste. In the sea there are a number of static factors and dynamic forces which determine the extent to which these desirable pollution-preventing processes can occur.

Geography of a given coastal marine area provides the confining horizontal boundaries within which the dynamic processes can act. Configuration of the bottom topography imposes a vertical limitation on these processes. The bottom contours can influence the degree of turbulent mixing that occurs when a current flows past.

Turbulent mixing provides the dilution mechanism, whereas advection (currents) provides the transport and dispersion. Three causes in the sea contribute toward mixing and advection—tides, freshwater runoff and winds. The tide is another feature of the sea which makes it different from the freshwater environment. The rhythmic rise and fall of sea water provides mixing and advection, the extent of which depends on the geography and topography of the particular area. In channels connecting large bodies of water, the tides can be very effective in mixing the wastes with the sea water, vertically and horizontally, and then transporting them out of the area. The magnitude of tidal mixing and transport is dependent on the range of the tide, other factors being equal. Along the British Columbia coast the range increases from south to north, being about 10 feet adjacent to Vancouver and 20 feet in the Prince Rupert area during spring tides.

Freshwater runoff renders an effect in the sea similar to that present in a river. The seaward flow of fresh water over the sea water provides a vehicle for transporting the wastes out of the area of pollution toward the open sea. By entraining sea water from below, however, this freshwater layer may, in fact, create a much greater volume of water for dilution and transport than that available from the original runoff. To replace the sea water removed by entrainment in the fresh water, there is a net flow of sea water inward at intermediate depths.

Winds in the sea, as in lakes or streams, provide mixing mainly in the upper layer, although the depth of this layer in the sea can be quite large. They can also effect transport of wastes in the surface layer through wind-driven currents. The greatest advantage of winds as a mixing and dispersing force can be gained in open coastal waters where a strong wind blows offshore.

Representative cases of sea disposal of pulp mill wastes in British Columbia

British Columbia pulp mills dispose of their wastes into a variety of marine areas. These areas can be classified simply on a geographical basis into three categories: inlets, partially-enclosed embayments, and tide-swept channels. Examples of these basic types are described in the following marine areas receiving wastes from pulp mills located on the British Columbia coast.

(a) Cousins Inlet

A relatively favourable condition for waste disposal avails itself at the head of Cousins Inlet (Figure 6), about midway along the British Columbia coast between Vancouver and Prince Rupert. The pulp mill at Ocean Falls discharges its effluent into a fairly large flow of well-oxygenated fresh water coming from the tailrace of the hydro-electric power plant nearby (Figure 7). The effluent is a mixture of wastes from a diversified production of sulphite and kraft pulp as well as newsprint and specialty papers. A dam controls the discharge of fresh water the year around so that even during the dry spell of

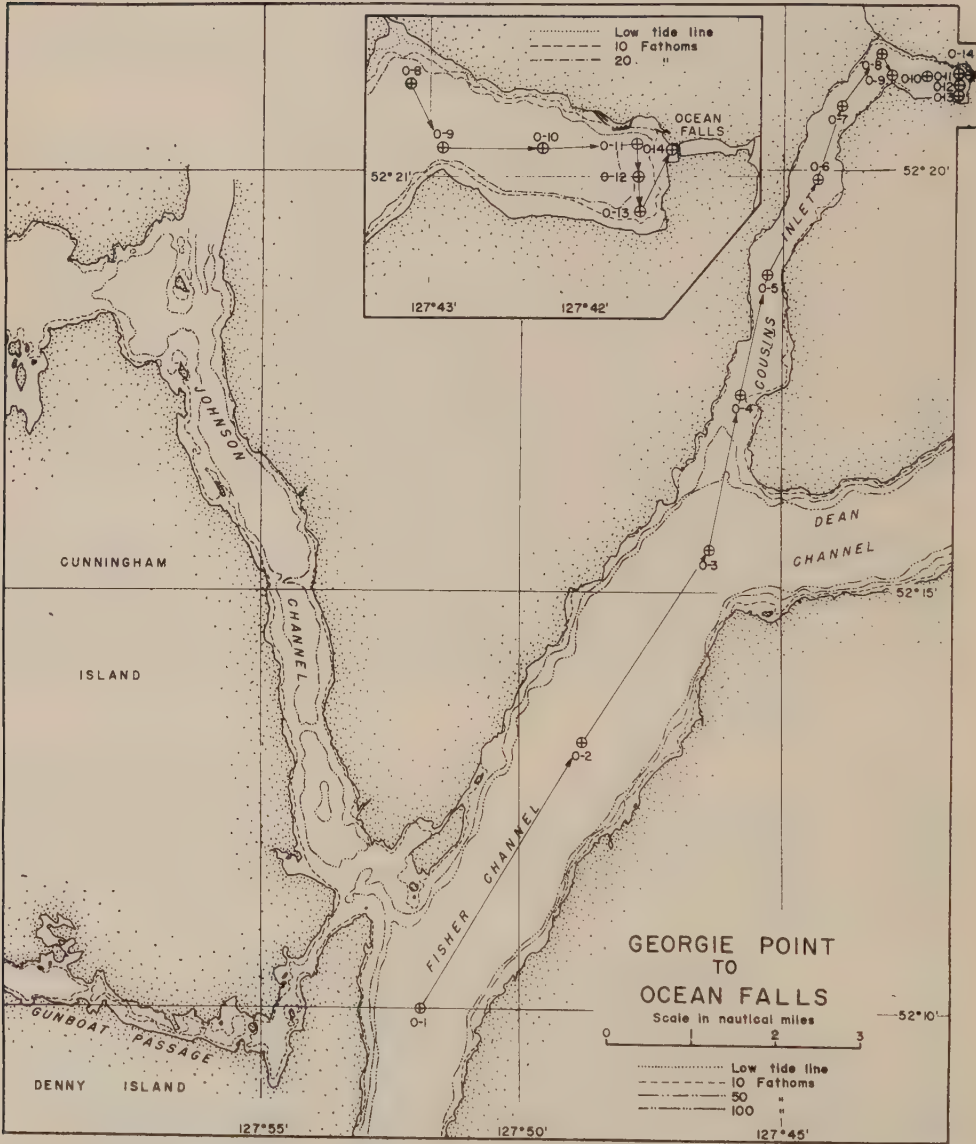


FIGURE 6. Chart of marine waters near Ocean Falls showing stations occupied in Fisher Channel and Cousins Inlet during a survey, 19-21 September, 1961.



FIGURE 7. Ocean Falls on the Link River, at the head of Cousins Inlet, where a mill of diversified pulp and paper production discharges its wastes into the tailrace from an hydroelectric plant.

late summer there is a flow of fresh water to remove the wastes effectively. The fresh water flows seaward at the surface, creating a fairly strong net current toward the sea. As in the case of Alberni Inlet (Figure 4), there is a strong advantage in discharging of pulp mill wastes into the surface water of Cousins Inlet.

Typical of this type of inlet in summer, there is a large stratification in salinity, temperature and density as shown on vertical sections in Figure 8. This stratified condition prevents any overturn of the water in late autumn and thus leaves the deep water in a relatively stagnant state. Although the temperature stratification was quite large at the time of the survey in September, 1961, its effect on the stability of the water is small compared to that of salinity.

The dissolved oxygen concentrations (Figure 9) in all parts of Ocean Falls Harbour were quite high, 8.9 mg/l (milligrams per litre) in spite of a moderate input of spent sulphite liquor. Within the inner harbour, there was a rapid diminution of dissolved oxygen with depths below 20 m, from concentrations of 3 mg/l at 20 m to near zero in the bottom 30-metre layer.

Closely allied with dissolved oxygen, the pH followed the usual pattern of vertical distribution in inlets, with relatively high values near the surface and considerably lower pH near the bottom (Figure 9). Surface pH in the inner harbour was comparatively low

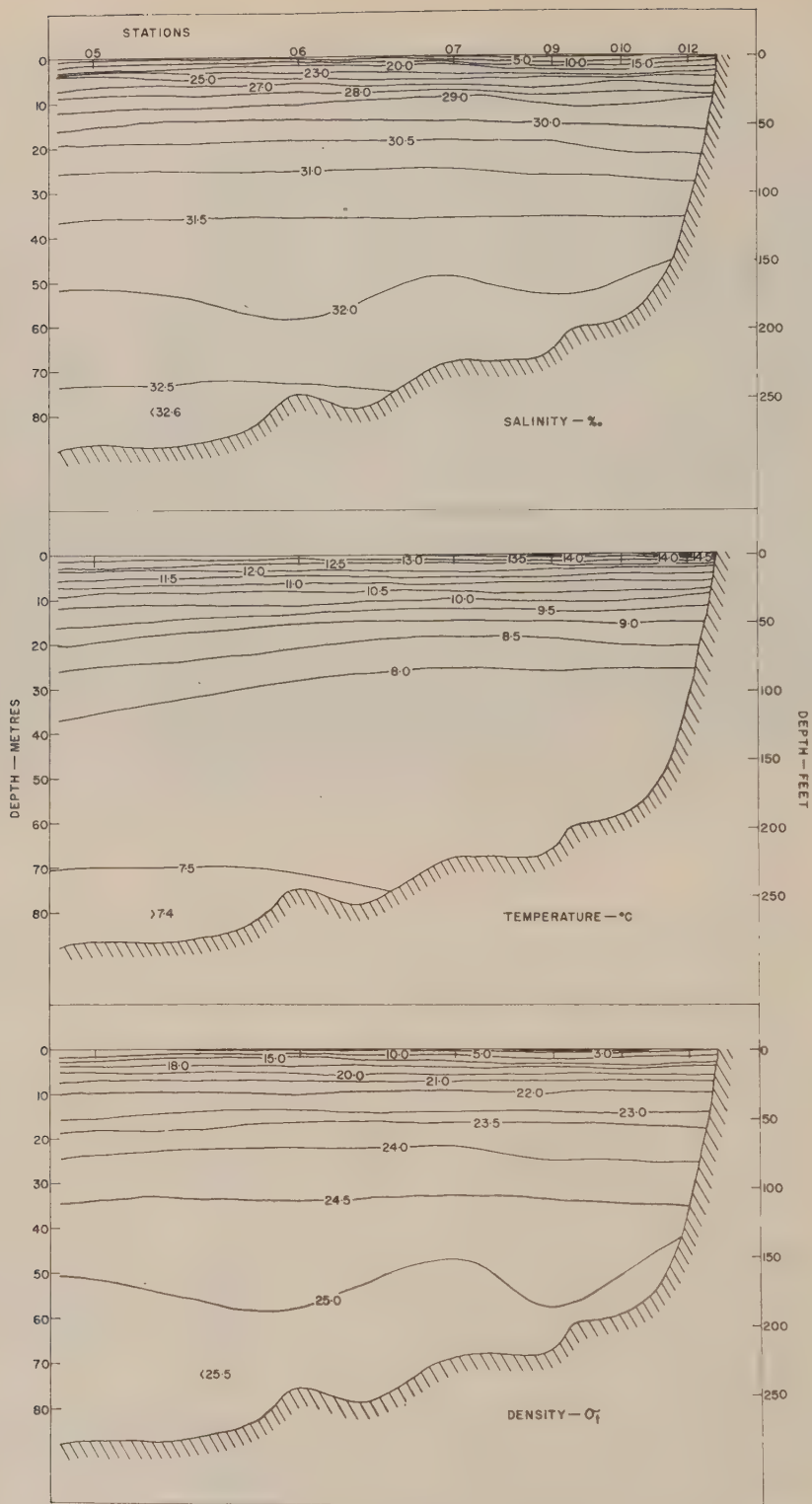


FIGURE 8. Longitudinal sections of Cousins Inlet giving the vertical distributions of salinity, temperature and density (σ_t), September, 1961.

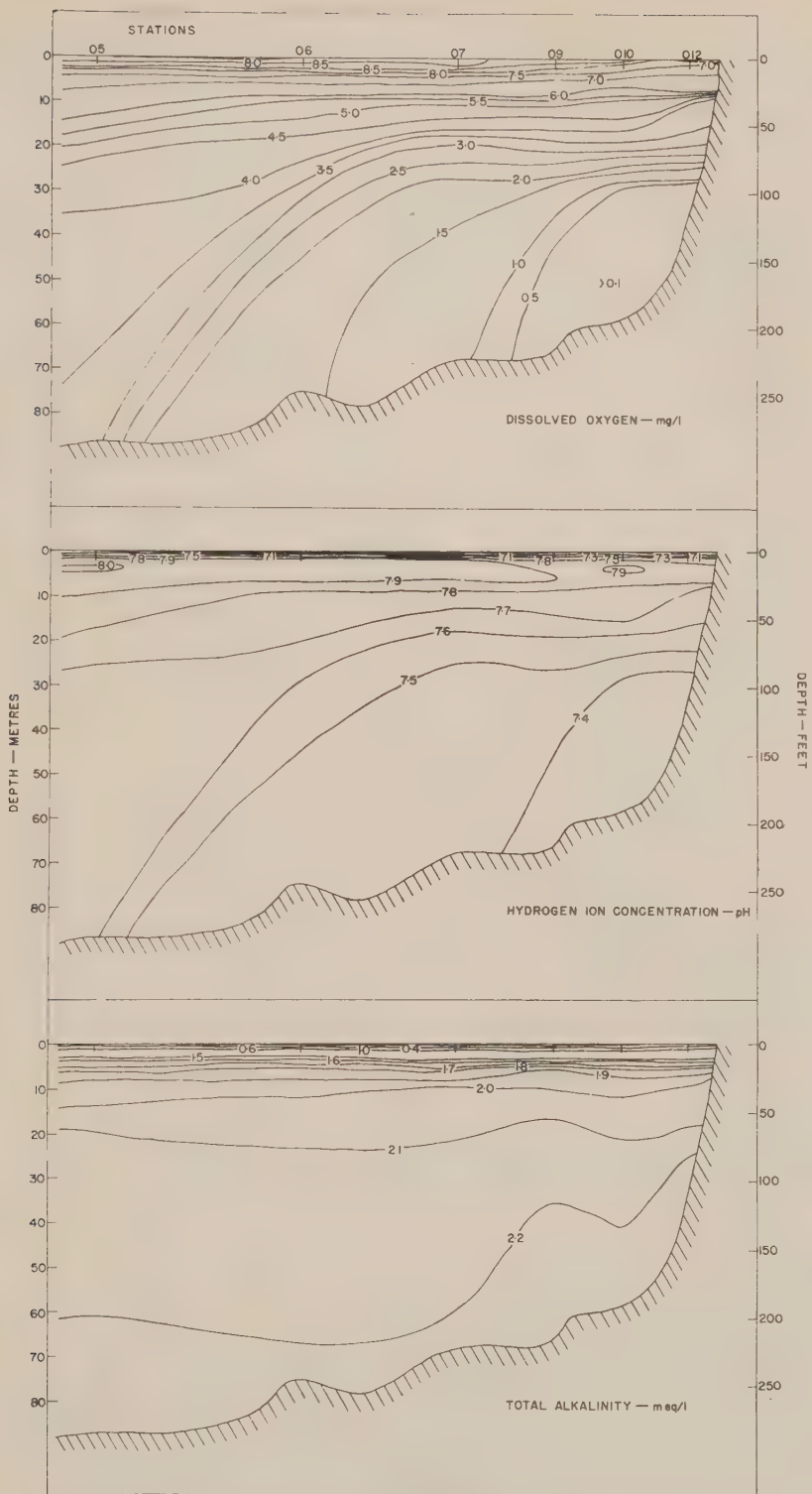


FIGURE 9. Longitudinal sections of Cousins Inlet giving the vertical distributions of dissolved oxygen, pH and total alkalinity, September, 1961.

(ca. 7.0), partly as a result of inflow of acidic wastes and partly because of presence of near-neutral fresh water. In the mixing zone between the surface and 10 m, the pH approached that for normal sea water, about 7.8. There was a sharp dip in pH from about 7.8 at 10 m to 7.4 at 30 m. The pocket of low pH in the bottom water at the upper end of the harbour corresponded to the pocket of low dissolved oxygen concentration.

Total alkalinity values were very low at the surface, around 0.4 meq/l (milliequivalents per litre), increasing to 2.0 at 10 m and about 2.2 meq/l at 50 m (Figure 9). In this area, as in other polluted or clean marine waters, the alkalinity is primarily a function of the salinity, being approximately proportional to the salt content.

The very low dissolved oxygen concentrations in bottom waters at the upper end of Ocean Falls Harbour is probably a manifestation of long-term effects of accumulation of pulp mill suspended solids. The mill has been in operation since about 1913, and since that time there has been a continuous deposition of fibres, bark and wood chips into the bottom sediments of the harbour. Anaerobic decomposition has apparently set in and, judging by the offensive odour, high hydrogen sulphide concentrations are present in both the mud and in the water immediately above it. A thick, slurry-like layer of decaying fibres with a strong odour of hydrogen sulphide was noted from bottom sampling. No living animals were found in any of the bottom samples for a considerable distance down the inlet. This area is of little concern to fisheries, inasmuch as there are no salmon runs this far up the inlet, the falls creating a natural obstruction. It is unlikely that the type of pollution that exists here would seriously affect salmon in any case, since there is good flushing and oxygen concentrations are high in the upper layer where salmon are normally found. Herring apparently move into the area quite regularly. However, crabs and other bottom fauna indigenous to the inlet would have been wiped out long ago.

A major problem, even in a comparatively deep harbour like Ocean Falls, is that periodic dredging must be conducted to keep the waters accessible for deep-sea shipping. This is not only costly, but the activity of a dredge disturbs the anaerobic bottom sediments and stirs up oxygen-deficient water, sometimes containing toxic hydrogen sulphide, into surface waters frequented by fish. A kill of fish in Alberni Harbour was attributed to such stirring up of bottom waters by dredging (Hourston and Herlinveaux, 1957). To perpetuate the harmful effect of the decaying fibres and spread it further afield, it is common practice to dump the dredged material into deeper water only slightly seaward of the dredged area.

(b) Porpoise Harbour and Wainwright Basin

These bodies of water are part of a partially-enclosed embayment system. The basins are connected by constricted channels through which there is a swift flow of water on every tide. The tidal range in the Prince Rupert area is quite large, but it is able to effect only a minimal flushing of the inner basins with each tidal exchange. The large tidal amplitude of open Chatham Sound is damped, presumably by the constricted channels through the basin system (Figure 10), so that the tidal range in Morse Basin is comparatively small.

A high-dissolving grade cellulose sulphite pulp mill on Watson Island discharges wastes into Wainwright Basin. This mill has been in operation for approximately ten years. At Port Edward nearby are fish-processing facilities, consisting mainly of a cannery and reduction plant which discharge a certain amount of organic waste into Porpoise Harbour. This, along with the small discharge of domestic sewage, is probably insignificant compared to the sulphite pulp wastes in the total pollution load on Porpoise Harbour.



FIGURE 10. Chart of waters in the Prince Rupert area showing locations of stations occupied in a survey, 15-18 September, 1961.

Distributions of salinity, temperature, and density (Figure 11) show generally well-mixed conditions, especially at Zanardi Rapids. Intrusion of high-salinity water from Chatham Sound through Porpoise Harbour can be inferred from the high bottom salinities of the outer harbour. The low-salinity water at the surface in Wainwright Basin arises from the effluent and a stream, Wolf Creek, discharging nearby.

The non-conservative properties, i.e., those properties affected by biological processes, showed a particularly interesting effect of the pollution (Figure 12). Dissolved oxygen

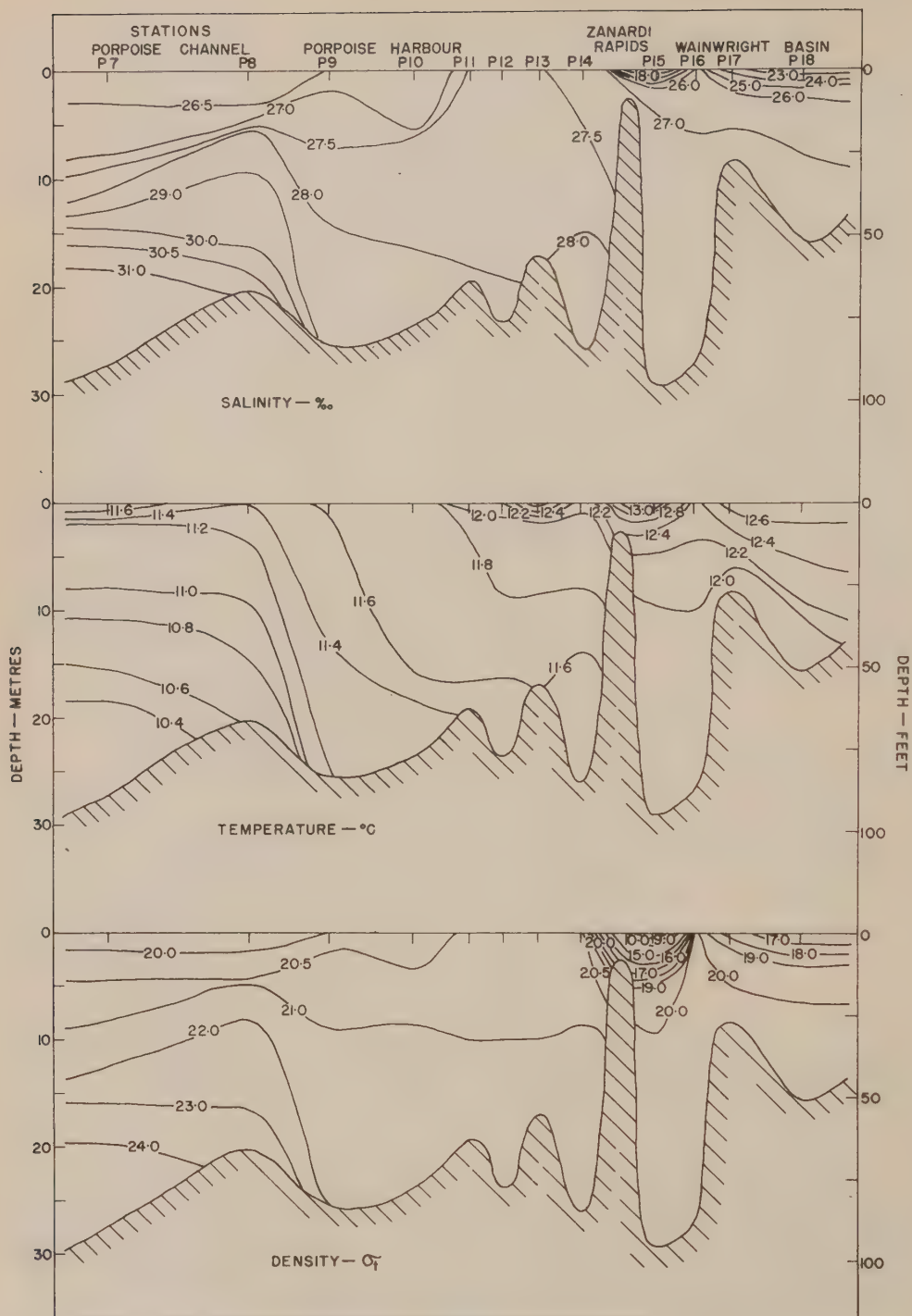


FIGURE 11. Salinity, temperature and density (σ_t) distributions in a vertical section through Porpoise Harbour and Wainwright Basin, September, 1961.

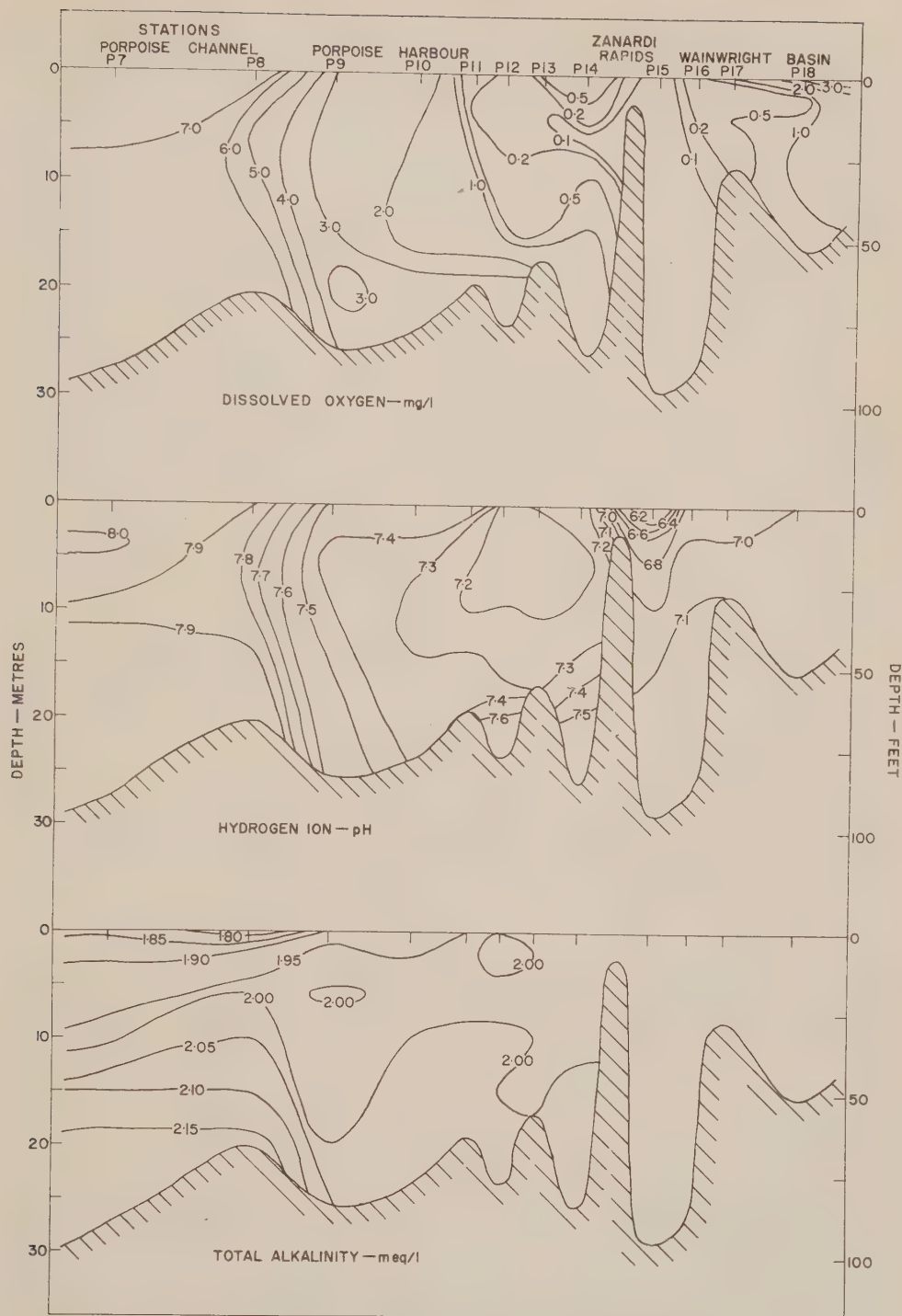


FIGURE 12. Dissolved oxygen, pH and total alkalinity distributions in a vertical section through Porpoise Harbour and Wainwright Basin, September, 1961.

concentrations ranged from 0 to 5 mg/l from Wainwright Basin to Porpoise Channel. It is certainly a useful criterion of water quality here. A horizontal gradient of oxygen concentration generally existed from the area of high pollution to the clear water at the approaches to Porpoise Harbour. Some intrusion of higher dissolved-oxygen water near the bottom was noted at the Porpoise Channel approaches to Porpoise Harbour. The pH distribution followed a similar pattern to the distribution of dissolved oxygen with a horizontal gradient as a result of the vertical mixing. The lowest pH's were found at the channel discharging wastes into Wainwright Basin. Values of 6.0 were found near the surface at Station P15, from where there was a gradual increase to values of 8.0 at P9 in Porpoise Channel. Total alkalinities were quite uniform, around 2.0 meq/l, in Wainwright Basin and Porpoise Harbour.

This whole area is quite interesting biologically. Judging from the diversity of shell remains, the bottom fauna in deeper turbulent waters and in the intertidal zone were quite rich at one time. The profusion of animal life is typical of well-mixed areas along the British Columbia coast. In the intertidal zone were found many shells of molluscan shellfish that apparently thrived here before pollution set in. A few living organisms were collected for later identification. Barnacles, a few small crabs, limpets, and gastropods were noted in the intertidal zone near Zanardi Rapids. In the bottom muds near the pulp mill and cannery there were primarily polychaete worms. However, one small sea urchin was picked up near the middle of Porpoise Harbour, where surface pollution was quite high but dissolved oxygen values were at a moderate concentration near the bottom.

Curiously, large numbers of amphipods were found in the surface water and on the bottom, particularly in the upper end of Porpoise Harbour where dissolved oxygen concentrations were low. Swarms of these organisms were seen near the surface alongside of the survey ship. It is possible that they were seeking the higher oxygen available at the surface of the water. No plankton hauls were made but samples were easily picked up with a bucket. The amphipods were identified as mostly *Allorchestes angustus* with some *Anisogammarus pugettensis*, both of which are fairly common inshore forms of the North American Pacific coast (Waldichuk and Bousfield, in press). They are usually confined to the bottom but may have been stimulated into a free-swimming state by the polluted conditions.

The region near Prince Rupert has supported a large herring fishery in the last few years. About 30,000 tons of herring were taken in Area 4, particularly in Morse Basin and some in Wainwright Basin, during the 1960-61 fishing season. Fishermen reported taking seine hauls of dead herring out of Wainwright Basin in February of 1961. In view of the low dissolved oxygen concentrations found there during the September survey, other herring kills may have occurred, but were unnoticed because the dead fish tend to sink to the bottom.

(c) Discovery Passage

This is a good example of a tide-swept channel in British Columbia. A pulp and paper mill has been in operation for about ten years in Duncan Bay, bordering on Discovery Passage (Figure 13). In our surveys over the years, there has been no evidence of pollution encroaching on the clear waters of Discovery Passage. The turbulent mixing by the tides and the swift currents ensure rapid dilution and dispersion of any wastes. In a survey made there during October, 1961, the water was noted to be very clear, in fact as clear as

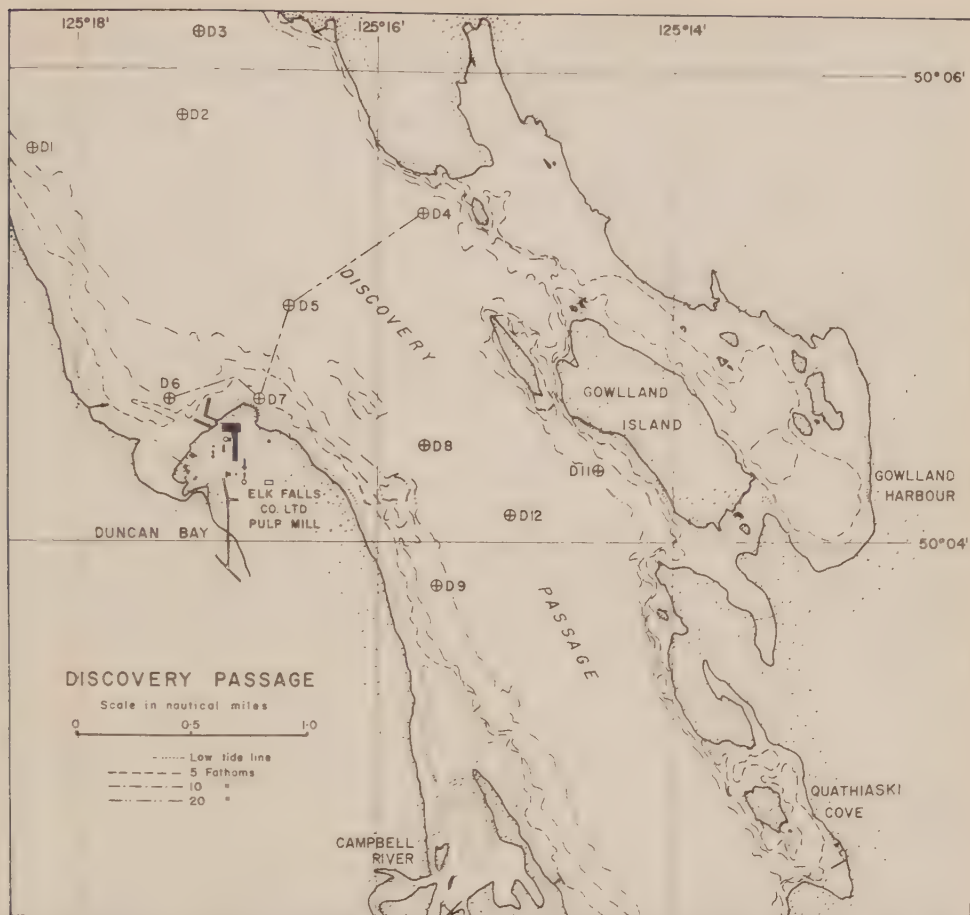


FIGURE 13. Chart of Discovery Passage showing stations occupied in a survey, 12 October, 1961.

that seen anywhere in inshore waters on this coast. Kraft mill effluent concentrations were low, except in the immediate vicinity of the mill sewer outfall. Secchi disc readings fell into the range of 8-10 m outside the "boil" at the outfall. These compare with 1.3 m in Alberni Harbour, 5-7.5 m in the lower part of Alberni Inlet, 4-9 m in unpolluted Muchalat Inlet and 13 m on the open west coast of Vancouver Island.

The distribution of variables (Figure 14) in vertical section shows the effects of intensive mixing which takes place on every tide. Except in the relatively sheltered waters of Duncan Bay, there was very little stratification in salinity, temperature or density. Salinity variation from surface to bottom in mid-channel seldom exceeded a few tenths of a part per thousand. Non-conservative properties also exhibited little variation with depth, although dissolved oxygen concentration decreased by as much as 1 mg/l from top to bottom. The water was under-saturated with dissolved oxygen at all depths, and this seems to be a normal condition in turbulent waters at this time of year. There appeared to be vertical homogeneity in pH and total alkalinity with values near 8.0 for the former and 2.0 meq/l for the latter.

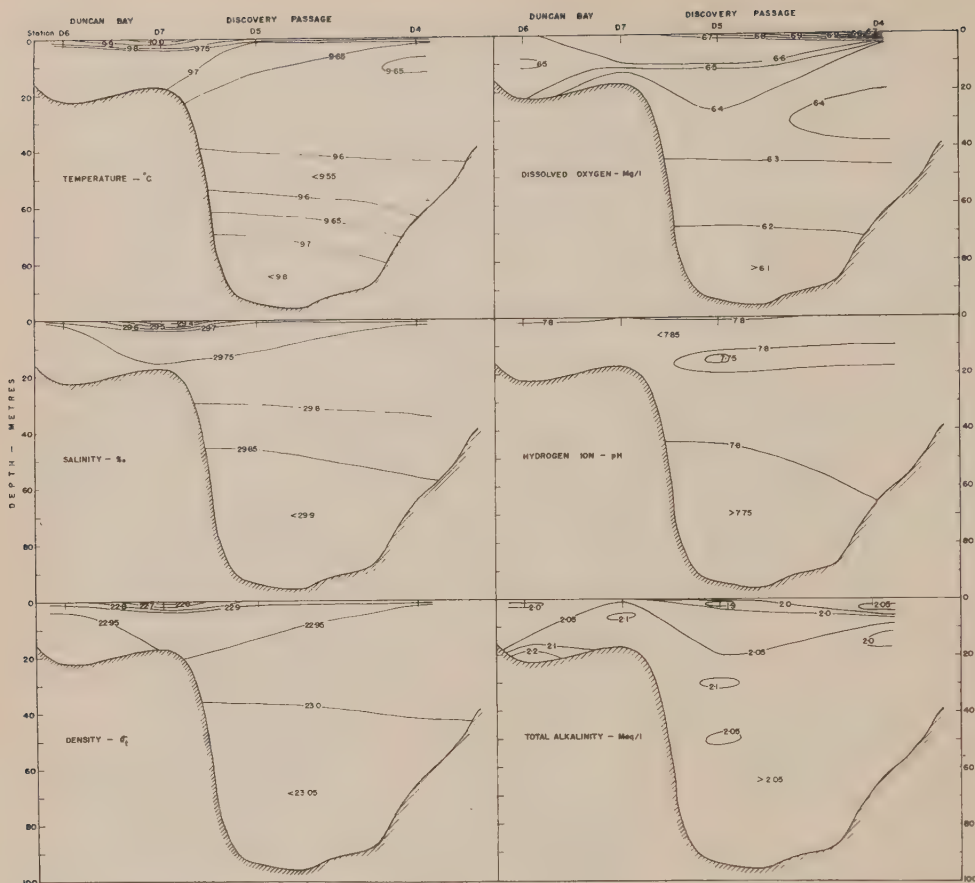


FIGURE 14. Distributions of various properties in a vertical section across Discovery Passage into Duncan Bay, October, 1961.

Bottom samples have been obtained wherever materials were present that could be collected with a clamshell-type bottom sampler. Generally, the bottom is rocky with large boulders and coarse gravel swept clean by the intensive turbulence and strong currents present in the passage. Even at a station adjacent to the outfall, it was impossible to pick up any deposited fibres or other wood materials with our type of sampling equipment. Except for slight sedimentation under the more quiescent conditions in small embayments along the shore, it is not anticipated that any significant deposits of these particulate residues from wood pulping will occur in Discovery Passage.

A giant barnacle, *Balanus nubilus*, was captured in one bottom sample not too far from the point of discharge of pulp mill wastes. This suggests that the environment for these bottom-dwelling organisms, which prefer clean, turbulent waters, has not been too seriously altered.

Prediction of dilution and dispersion

One of the objectives in our oceanographic work is evaluation of a marine system for its ability to dilute and disperse wastes. Although rough estimates can be made in all

situations, an inlet is the only type of marine system which lends itself to a reasonably good quantitative assessment of flushing characteristics. A partially-enclosed embayment is least amenable to quantitative techniques for prediction of dilution and dispersion. There are usually a number of variables affecting circulation in such an embayment so that a standard scheme of prediction is difficult to establish. At one time of year, when precipitation is large, the runoff may be the factor dominating the circulation. During other periods, tides may strongly influence water movement and hence dispersal of wastes; yet at other times, when strong persistent winds prevail, wind mixing and wind drift may prominently assist in the dilution and dispersion of wastes. Under such circumstances, the empirical approach using floats and other current-measuring devices during different conditions of wind, tide and runoff seems to be the most rewarding for providing information on waste disposal sites.

In a tide-swept channel, where complete vertical mixing takes place and wastes transported in one direction on one tidal cycle are not returned on the next, the flushing characteristics can be estimated by simple dilution and transport calculations. The volume of water passing through in one direction on a tidal cycle can be evaluated from the channel cross-section and the average current velocity. This volume of water is assumed to be available for dilution of wastes when complete mixing takes place. If only partial mixing occurs and some of the waste is removed by diffusion, then prediction of dispersion requires a more complex mathematical approach in which eddy diffusion coefficients must be applied.

Prediction and control of pollution in Alberni Inlet

Work carried out by Tully (1949) to determine the effect of a proposed sulphite pulp mill in Alberni Inlet has provided a means for prediction of pollution in subsequent pulp mill problems. Alberni Inlet (Figure 15) receives a fairly large runoff, with the major contribution of fresh water coming from the Somass River. Fresh water entering the inlet flows over the surface of the sea water, creating considerable density stratification. In a sense, the behaviour of wastes discharged into surface waters of Alberni Inlet is similar to the situation in a river. The difference is in volume of water available for dilution and in the amount of dissolved oxygen supplied to satisfy the oxygen demand of the waste. The fresh water entrains sea water at its lower boundary as it flows seaward. Thus there is progressively greater dilution as the mouth of the inlet is approached. The upper zone of brackish water, however, does not thicken appreciably (Figure 16), and the net result is an increasing current to transport the larger volume as one advances seaward in the inlet. As the Somass River discharge increases, the volume of water in the upper zone becomes much greater and the rate of seaward flow increases proportionally (Figure 17).

Dissolved oxygen was used by Tully (1949) as a criterion in estimating the maximum permissible waste discharge into Alberni Inlet from a sulphite pulp mill. Partly because of the threat of intolerable pollution from sulphite wastes and partly because of economical factors involved in the pulp trade, a kraft mill instead of a sulphite pulp mill was ultimately installed at Port Alberni. A nominal production of 220 tons per day of unbleached kraft pulp was maintained for the first eight years of operation. Wastes from this small production showed no obviously serious effect on the water quality or on the fisheries of Alberni Inlet.

In 1954 the company planned a major expansion of the Port Alberni pulp mill and a prediction was desired of the effects the wastes from this expanded production would



FIGURE 15. Chart of Barkley Sound and Alberni Inlet showing stations occupied in periodic surveys.

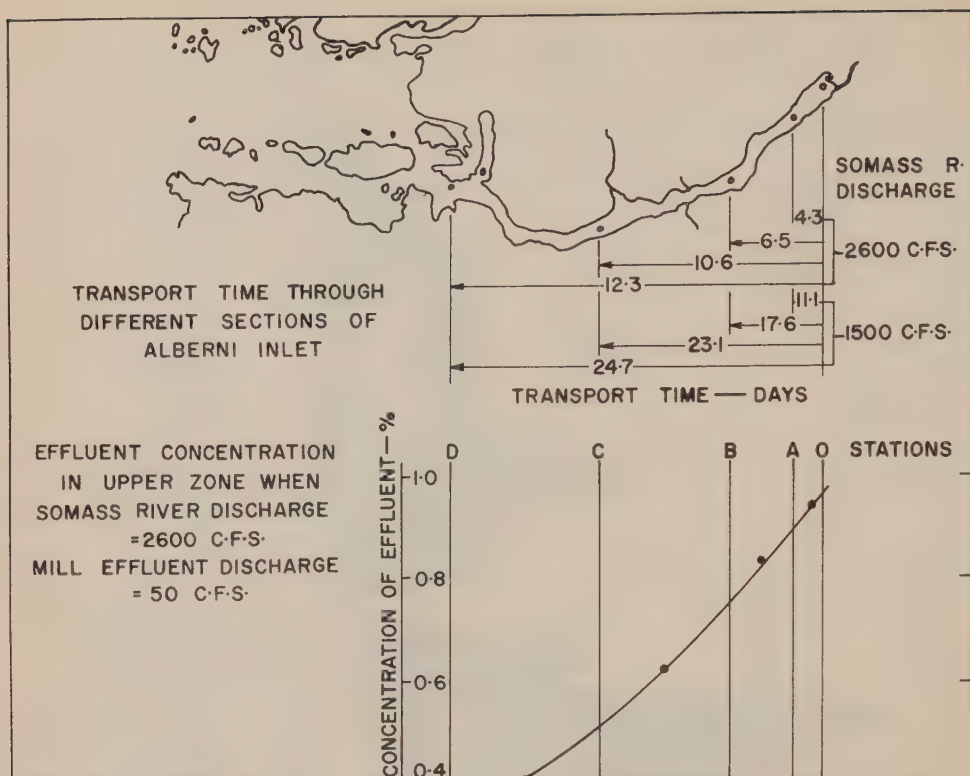


FIGURE 17. Transport time and dilution for effluent released at the head of Alberni Inlet under two rates of discharge of the Somass River.

have on the inlet waters. After extensive B.O.D. (Greer *et al.*, 1956) and bio-assay tests (Alderdice and Brett, 1957) were made on composite effluent from a full-bleach kraft pulp mill, it was found that dissolved oxygen is the critical factor when the oceanographic conditions of Alberni Inlet are considered. If sufficient water is available in Alberni Harbour to satisfy the dissolved oxygen demand of the kraft mill effluent, then toxicity to salmon, at least in the lethal range, is not a problem.

Dissolved oxygen in the upper zone of Alberni Inlet (Figure 16) is supplied mainly by wind aeration locally and in tributary waters, although a certain amount is introduced by the photosynthetic processes of phytoplankton. Solubility of oxygen in sea water depends on the salinity and temperature. During the warm summer period the solubility is lower than it is during the colder months of the year. There are certain naturally-occurring processes, such as phytoplankton blooms and decomposition of dissolved organic and detrital material, which introduce further seasonal variations in dissolved oxygen content of the water. From the observed proportion of fresh water in Alberni Inlet at various flows of the Somass River, the volume of the upper zone in Alberni Harbour was evaluated for different months of the year. Observed seasonal variation of oxygen saturation values was used to compute the mean daily amount of dissolved oxygen available in the upper zone of Alberni Harbour. Seasonal variation of this oxygen availability shows a period of low supply in August and September (Figure 18). Dissolved oxygen requirements

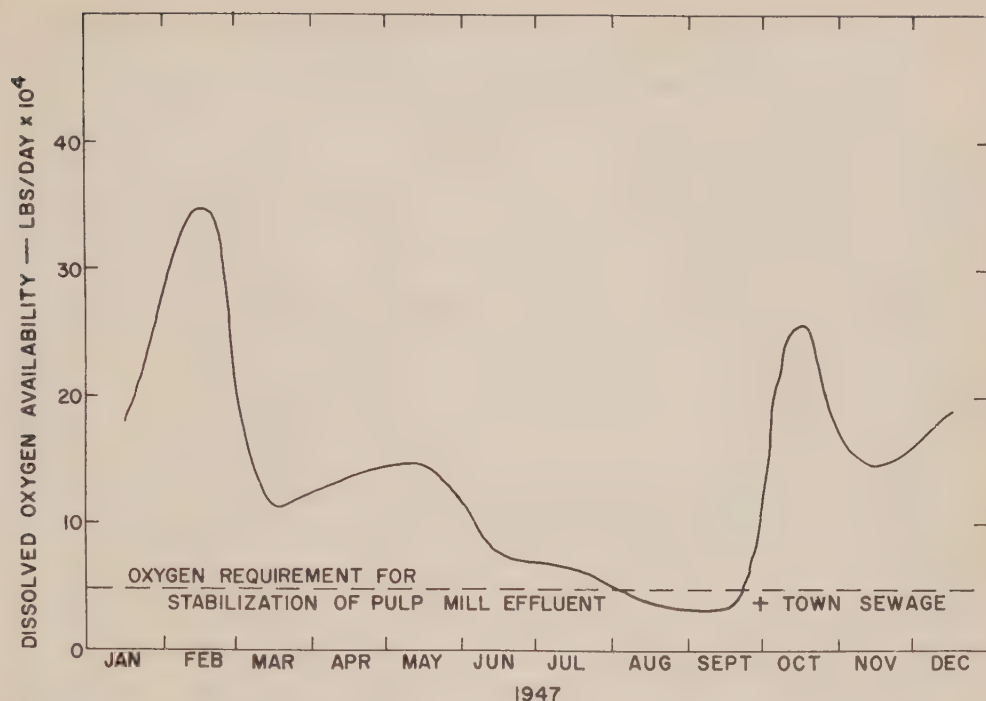


FIGURE 18. Seasonal variation of dissolved oxygen availability in the upper zone of Alberni Harbour.

based on a mill producing 500 tons of full-bleach kraft pulp per day would require that the production either be reduced or completely stopped during the critical summer months. To overcome this problem, the Somass River had to be controlled to give a larger flow in late summer.

Evaluation of the minimum permissible river discharge entailed a knowledge of the minimum oxygen requirement for fish. The work of Alderdice and Brett (1957) showed that the amount of oxygen required for respiration of young salmon is not constant but increases with the concentration of kraft mill effluent. This relationship applies also in reverse, where the tolerance of fish to a toxic pollutant is influenced by the concentration of dissolved oxygen. A salmon is more likely to die or become distressed when it is subjected to a given concentration of a toxic substance in water having an adequate, although a low, dissolved oxygen concentration, than in one having a high oxygen concentration. More recent research by Alderdice (personal communication) of the Fisheries Research Board's Nanaimo Biological Station has shown that the other environmental factors, such as temperature and salinity, also affect the tolerance of fish to various pollutants. Thus, for young coho salmon, there is an optimum level of temperature at about 7°C (45°F) and one of salinity at 10‰. Resistance of salmon to kraft black liquor solutions drops as the temperature and salinity depart in either direction from these optimum values.

As a first approximation from the earlier bio-assay work (Alderdice and Brett, 1957), by taking a mean temperature and salinity in the upper zone of Alberni Harbour for the month of August, a curve of oxygen requirements for salmon at different concentrations of KME was obtained (Figure 19). The dissolved oxygen available after wastes from a

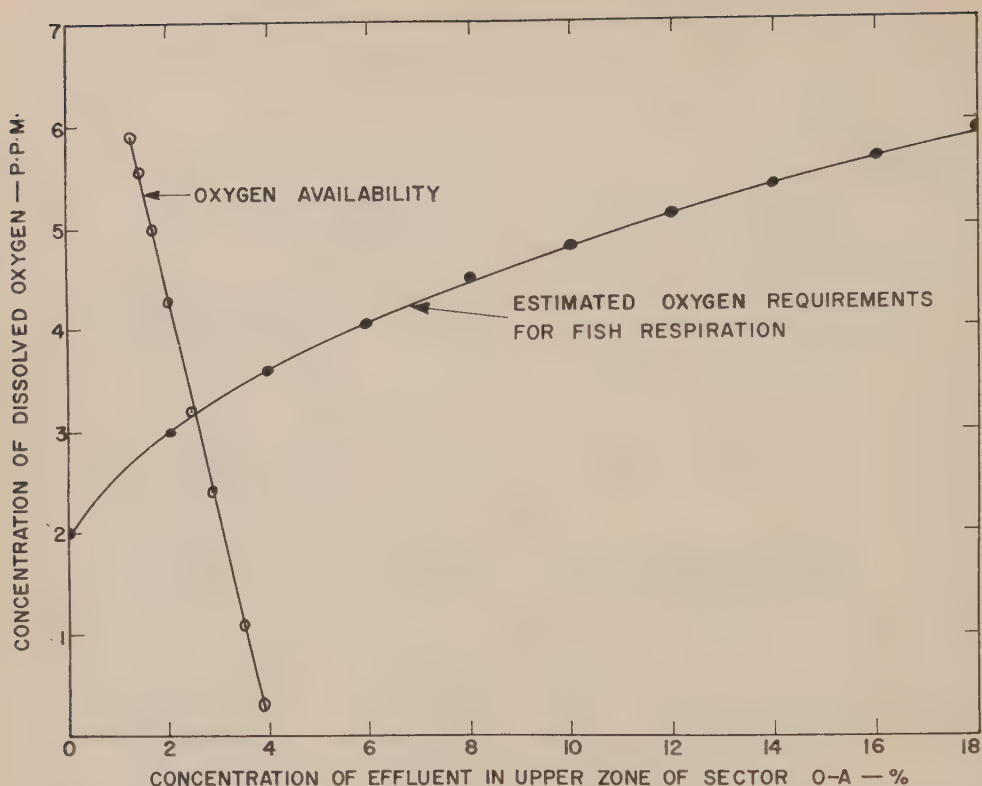


FIGURE 19. Relationship of net dissolved oxygen availability to effluent concentration in the upper zone of sector O-A of Alberni Inlet (see Figure 17), and the variation with effluent concentration of oxygen requirement of fish.

500-ton per day full-bleach kraft pulp mill are stabilized is given on the same graph for different dilutions, i.e., for varying discharges of the Somass River. The intersection of the two curves gives an estimate of the effluent concentration where dissolved oxygen becomes a limiting factor for fish survival. At effluent concentrations greater than about 2.5 per cent, death of the fish can occur by hypoxia.

Translating the foregoing data into some basis for engineering control of pollution in Alberni Harbour requires curves of variation of dissolved oxygen availability with Somass River discharge. From the relationship of the amount of oxygen present in the upper zone of Alberni Harbour to inflow of fresh water, a curve of total dissolved oxygen present with variation of river discharge was obtained. Availability of dissolved oxygen after fish requirements are satisfied has been computed for a range of Somass River discharges. These curves are plotted in Figure 20, showing the oxygen required for stabilization of wastes from 500 tons per day of bleached kraft pulp. The dissolved oxygen required, some 4.8×10^4 lb per day, can be supplied by the discharge of about 970 c.f.s. of the Somass River plus the entrained sea water. Although the increased production of the Port Alberni pulp mill was not realized exactly in terms of 500 tons per day of full-bleach kraft pulp, the ultimate minimum Somass River discharge requirement was very nearly 1000 c.f.s. It has been maintained above this level by dams on tributary streams since expanded production went into effect.

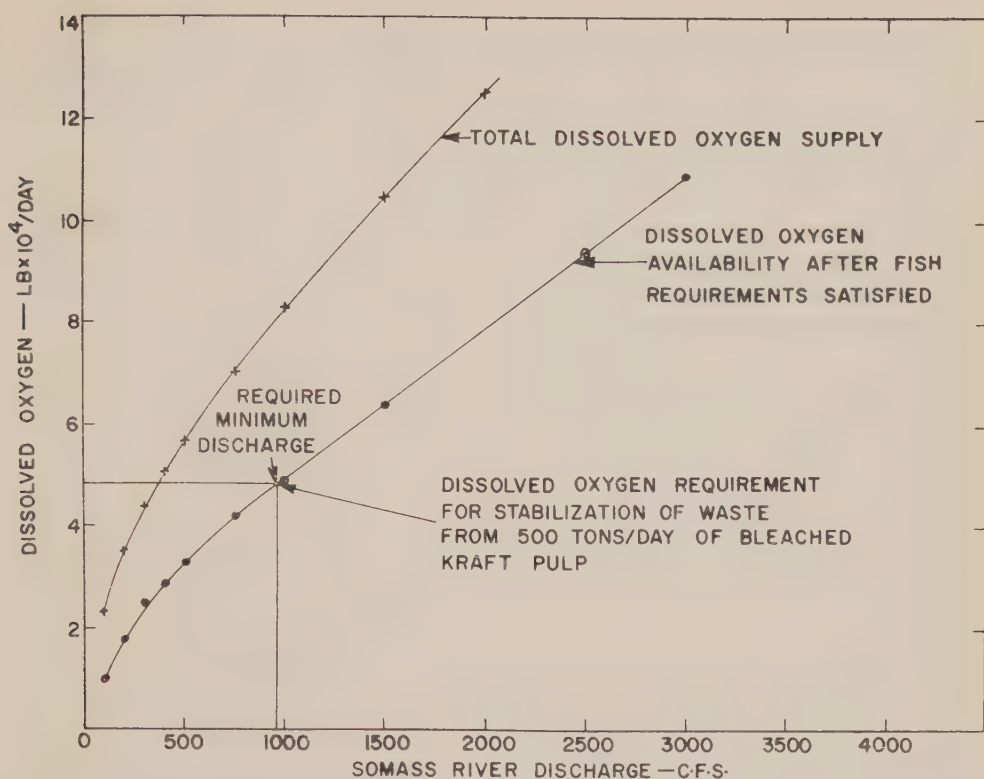


FIGURE 20. Variation of total dissolved oxygen supply and oxygen availability, after fish requirements are met, with Somass River discharge.

From Figure 19 it can be seen that an effluent concentration of 2.5 per cent exists in the upper zone of Alberni Harbour when the river discharge is just sufficient to satisfy the oxygen requirements for fish after the pulp mill wastes are stabilized. This is an average calculated percentage of effluent and, in reality, there are much higher local concentrations near the mill sewer outfall. Bio-assays have shown that, under the salinity and temperature conditions prevailing in Alberni Harbour during late summer, 4.8 per cent of KME is the limiting concentration for toxicity. When the lower dissolved oxygen concentration present at that time of year in the "oxygen sag" area of the outer harbour is taken into consideration, the limiting concentration is lowered to 2.5 per cent. This is still higher than the concentration observed at the harbour entrance (Waldichuk, 1956), or that expected during the minimum permissible discharge of the Somass River required to provide the necessary oxygen for stabilization of the waste plus average minimum dissolved oxygen concentration for fish.

Chronic or long-term effects of pulp mill wastes

While prediction of the immediate effects on water of the dissolved constituents present in pulp mill wastes can often be made quite satisfactorily, the prediction of cumulative results of suspended particulate materials is much more difficult. In the marine environment, the flocculating property of sea water causes sedimentation of the solids to occur near the outfall. This may have an advantage if the outfall is in some area remote

from the waters inhabited by bottom invertebrates and fish, and widespread deposition of the suspended materials is not desirable. However, the outfall is often located in such a way that the jet stream of fresh water flowing through the harbour will rapidly carry away the effluent. Under such circumstances, the deposition of fibres and other wood wastes may occur near the path of migrating salmon and trout.

From data taken a few years after a pulp mill commences operation and then again many years later, we have been able to note that deterioration of water quality and bottom characteristics has taken place in a marine system receiving pulp mill wastes. This has been observed in Neroutsos Inlet after a span of 40 years of sulphite pulp production at the Port Alice mill (Waldichuk, 1958). Conditions in Ocean Falls Harbour arising after nearly 50 years of pulp mill waste disposal have already been described. Although it is well known that chronic pollution conditions lead to eventually harmful effects, we do not fully understand the mechanism of this long-term change. Some of it may be the result of ancillary activities, such as shipping, oil spills, etc., associated with a growing industrial community.

In Alberni Harbour, there has been a continuous deposition of the suspended solids from the pulp mill effluent near the Somass River mouth over the past 13 to 14 years of production. Anaerobic decomposition occurs in the sediments, and hydrogen sulphide has been detected in the bottom of the northeast end of the harbour. Dissolved oxygen has been removed from the water overlying the bottom. Occasionally when the bottom is stirred up in dredging operations, a fish kill may occur (Hourston and Herlinveaux, 1957). There is also evidence that a progressive decline in dissolved oxygen concentration has been occurring in the poorly flushed, lower zone water of Alberni Harbour. The layer of low oxygen concentration near the bottom has been thickening upward and water having as little as 3 mg/l of dissolved oxygen has been sampled at 10 feet depth. The condition becomes most serious during years of warm, dry summers following winters when runoff and wind stirring are insufficient to flush out the bottom water.

Other areas have shown gradual deterioration over a period of many years of pulp mill waste disposal. Sometimes aggravation of the existing pollution by increased production of a pulp mill may render a marine area completely unfit for fish. A spill of black liquor or other toxic substance from a pulp mill may exhibit much more acute effects under a state of chronic pollution than otherwise might be the case. There is, no doubt, some acclimatization of surviving species to polluted conditions. However, the balance of nature has been shifted and only too little is known about the ultimate effects of such a shift.

Summary and conclusions

Pulp mill wastes in coastal British Columbia have produced a wide range of conditions in the recipient waters. The ultimate pollution which develops in a pulp mill area depends on the extent of recovery of the dissolved organic materials and suspended substances in the wastes and on the type of oceanographic system into which the wastes discharge. Raw wastes from a high-dissolving grade, cellulose sulphite pulp mill in the Prince Rupert area and a poorly flushed, partially-enclosed embayment system into which they discharge, combine to produce the most severe marine pollution yet encountered in British Columbia.

By hindsight, we can now show that most of the pollution problems could have been avoided. The proper selection of a mill site in an area where waters are turbulent and provide a large flow on each tide can do much to prevent intolerable pollution. Discovery

Passage is an outstanding example of such an area. Inlets will always be suited economically for pulp mills because of the availability of resources and transportation. Not all inlets, however, are suited for waste disposal.

A large runoff provides a good flushing medium for waste discharged into surface water. In areas where such runoff is not available, it may be possible to utilize deep saline water for immediate dilution. This can be achieved with proper design of a submarine outfall terminating in a diffuser. In waste disposal from the pulp mill at Crofton (Waldichuk, 1955), an immediate dilution of 1:20 has been possible by discharging through a diffuser at a depth of 10 fathoms. Caution must be used in design, however, to ensure that effluent is all carried to the surface to be transported seaward in the surface layer.

Long-term effects of pulp mills cannot be easily recognized and may be more serious than immediate effects that can be readily identified and corrected. This chronic pollution results mainly from cumulative developments arising out of waste discharge. In the sea, as in fresh water, deposition of particulate materials modifies the environment for bottom-living organisms which may be important sources of food for fish or humans. More basic research is required for a better understanding of long-term changes caused by pulp mill wastes. Until we have some of the needed information on cumulative effects, it will be necessary to impose safety factors, that may sometimes seem unjustified, in design of waste disposal facilities.

The objectives in prevention of pulp mill pollution are in no way incompatible with the principles of good housekeeping and economical operation of a mill. All materials which go down a sewer were purchased originally, and if economical recovery is possible, they constitute a gain for the pulp industry as well as for conservation of aquatic resources. Harmonious multiple use of waters by the forest industry as well as by fisheries can be achieved through sound planning. Site selection for a pulp mill should take into consideration the effective and safe disposal of wastes as well as the availability of raw materials, transportation and markets. Waste disposal facilities should be as much a part of the overall plan for a mill as the basic components of production. Fortunately, there is growing evidence for the acceptance of this attitude in the pulp mill industry of British Columbia.

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The Need and Value of Water Quality Criteria with Special Reference to Aquatic Life

by

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Introduction

Our usable supply of good fresh water, like our timber and mineral supply, is exhaustible. Due to an extensive educational campaign, it has been recognized for some years that our timber supplies are being rapidly depleted and that good forest management is essential if we are to have adequate supplies in the future. The need for the wise use and management of another of our basic resources, the soil, is also being recognized. However, another of our basic resources, water, has been so abundant in some areas that we have failed to recognize its great intrinsic value and the necessity for adequate and permanent fresh water supplies of the quality required for the various desired uses. Until very recently, few of us thought of the source of our drinking water, the permanence of the supply or its future adequacy for an increasing population and industry. There is a growing per capita use of water in this country. However, much is wasted as we let the tap drip, leave the sprinkler running until water runs down the gutter, or flood the land for irrigation until water collects in pools in low places. Such practices are not only wasteful but detrimental.

Other practices also have undesirable effects on our total water supply. Not too long ago the disposal of domestic waste was a personal problem and often was solved simply by pitching it out the window or door. In the cities such practices created a hazard for anyone using the streets and odours were a constant reminder of the problem. With the development of sewers and the water carriage of wastes, the problem became less apparent. When domestic wastes are mixed in underground sewers they become impersonal and most people do not assume responsibility for them. The easiest solution is to discharge the sewers below town, out of sight and out of mind but in the neighbour's drinking water. We wouldn't think of dumping our garbage on the neighbour's front lawn but putting our domestic wastes into his drinking water does not seem to carry a social stigma.

Such attitudes have had a long period of development. To the early settlers our water supplies appeared to be inexhaustible. It was only natural, therefore, that they should use the streams to carry away wastes and unwanted materials, even though these streams also often furnished their drinking water and were an important source of food. When population was sparse it seemed reasonable to assume that our streams could assimilate all our wastes and that their use for such purposes was economical and in the best interest of the community. These attitudes have persisted to the present time, at least in the minds of some. Until quite recently many felt that we could dedicate many of our streams to the carrying of wastes and that we could look forward to pollution becoming more widespread and severe. Many felt no particular concern over such developments as they did not

foresee that our streams would have to be cleaned up in order to assure an adequate water supply for our many future uses. In our headlong rush for "the better life", a greater population and so-called progress, we have not always considered even the short-term, let alone the long-term effects of our activities on our surroundings and on ourselves. With our rapid growth a snowballing process has developed; as our population and industry expand we need more and more good water, while at the same time the wastes from our expanding activities are rendering more and more of our waters unfit for many uses.

For many years the conservationists have been pleading for the protection of our water resources, but it has been only within recent years that there has been a general awakening, a better understanding of the situation and a realization that water shortages can develop even in areas which were well supplied with fresh water. It is now agreed that our water resources are exhaustible, that short supplies may limit growth in many areas and that attention must be directed toward the conservation of our water resources. Public interest in water resources has been aroused and many new boards, committees and agencies are coming into being for the survey, evaluation and management of water resources. Those who have studied our water resources problem are agreed that we must use our supplies wisely if they are to serve the needs of all the people.

Our freshwater resources are derived from rainfall and cannot be significantly increased by any known economically-feasible method. Ways to augment water supplies are being explored by the federal government. Several universities have research projects in this field and it is the consensus that methods will be developed for the economical conversion of sea water to fresh water. In coastal areas, freshwater supplies can be augmented by the conversion of sea water, but such practices are not generally feasible for inland areas because of the cost of transportation and the immense quantities needed.

The best means for increasing our inland freshwater resources is to use the water over and over again. The greatest obstacle to such reuse is water pollution which has rendered reuse of many of our waters difficult and costly. Pollution must be controlled if we are to have adequate water supplies for the future. If our waters are to be effectively and efficiently used and reused for a variety of purposes, each user must return his process or waste water to the source in a condition suitable for other desired uses. To do this it is essential that the quality of water required for each of the desired uses be definitely known. We do not have this knowledge at present. Such knowledge is a prerequisite for water reuse. Thus, in maintaining or restoring the suitability of our waters for selected uses our first task is the determination of the water quality characteristics which are required for each use. Definite criteria of water quality for each of the principal water uses must be set up before we can effectively treat waste waters to assure their suitability and that of the receiving water for other specific uses. We must know our objectives, that is, the water quality which is needed, before we can intelligently and effectively abate pollution and reuse our water resources. In fact, criteria are essential if we are to determine objectively where pollution exists, measure its severity, or evaluate control measures. Such criteria are the keys to effective pollution abatement and efficient water use and reuse.

The various uses of water may be roughly classified under eight categories: (a) Domestic and municipal; (b) Industrial; (c) Agricultural; (d) Aquacultural; (e) Recreational; (f) Aesthetic; (g) Navigational and (h) Power. Waste disposal has not been listed as a use of water resources since all wastes result from the eight main uses listed above.

Wastes resulting from each of these uses are, in part, characteristic of each. Municipal or domestic wastes are largely organic and their utilization by bacteria and other micro-organisms in the water may produce severe oxygen depletion. Industrial wastes may have great oxygen demands; they may be toxic to aquatic and other organisms; they may increase temperatures, produce turbidity and add settleable solids; they may add radioactivity; or they may taint the flesh of aquatic organisms. Formerly, agricultural wastes consisted largely of silt and other materials washed into streams and other waters as a result of land erosion. Recently, however, the new synthetic organic pesticides are being so widely and extensively used for the control of crop, garden and forest pests that they are becoming pollutants. Return irrigation waters can create problems as they may contain large amounts of dissolved solids which are undesirable. In addition, these waters are usually warm and may contain materials such as pesticides in concentrations that are harmful to aquatic life. Aquacultural wastes are chiefly organic, arising from the processing of fishery products, from hatcheries and from the activities of fishermen. Recreational and aesthetic uses of our waters produce only a few harmful waste products, principally sewage and wastes from motor boats. Wastes from navigational uses are largely domestic sewage, oil and motor exhausts and spills of material being transported. Power generation may add large quantities of hot water or, if the power is produced by water, may result in decreases in dissolved oxygen and changes in temperature or character of the water due to impoundment.

Although some data are available on the quality of water required for each of the eight major water uses, a great deal remains to be learned. We are in need of information on the long-term effects of certain trace elements found in drinking water and on the maximum safe levels of heavy metals and other materials when consumed over long periods. Information is greatly needed on the effects of the ingestion over extended periods of the various pesticides which may occur in water. Knowledge of the toxic effects of a variety of materials on plants and concentrations which are not harmful under conditions of continuous exposure is needed for the establishment of quality criteria for irrigation water. With the reuse of water, quality criteria for water used in industrial operations will become increasingly important. A knowledge of the water quality requirements of aquatic populations is basic for the protection of aquatic life and the effective abatement of pollution. These criteria are our main topic for discussion.

Water Quality Criteria for Aquatic Life

The basic purpose of water quality criteria for aquatic life is to restore and maintain environmental conditions that are essential for the survival, growth, reproduction and general well-being of the important aquatic organisms. Thus, a knowledge of these environmental conditions must precede the establishment of such criteria.

Basic Principles for the Establishment of Water Quality Criteria

In determining environmental requirements of aquatic organisms and in formulating water quality criteria, it must be constantly borne in mind that average environmental conditions are not necessarily a measure of a suitable environment. In fact, the average can be very misleading. It is the extremes of environmental conditions that govern. Extremes of even short duration can determine whether or not a species will be present in a certain area. If the water of a stream reaches temperatures that are lethal to trout on one day in

the year, that stream will not be a trout stream even though conditions may be satisfactory every other day of the year. Good pools and cover, abundant spawning areas and food, and suitable chemical conditions in the water supply will be of no avail for the maintenance of a natural population if lethal temperatures occur.

In ascertaining environmental requirements which are to serve as the basis for water quality criteria the researcher is determining specifications which must be met to provide water of a quality which will meet the need for which it is intended. In setting water quality criteria for a specific use, the research scientist must not be influenced by economic or other similar considerations. His task is to establish the quality of water which is required for a specific use. This he must do if the water is to serve that purpose. To do otherwise would make his entire effort a waste. In the implementation of water quality criteria for aquatic life the economics of the situation are taken into consideration when the water pollution control board or other enforcement agency decides what use or uses shall be given preference in a given stream or area. It should also be remembered that economic considerations, though important, are not always paramount. Public preference is a potent influence in determining pollution control programs.

In the investigations for the collection of data on the environmental requirements of aquatic life which are to serve as the basis of criteria for the restoration or maintenance of a suitable habitat, conditions as they exist in our waters must be taken into consideration. Levels or concentrations that can be tolerated for short periods should be determined. Such information would indicate levels which can be tolerated for infrequent or short period discharges, levels satisfactory for the passage of migrating fishes, and the possible effects of spills. In the determination of environmental requirements and satisfactory levels for materials added to the water, it must be recognized that mere survival or the ability to resist death for a time does not indicate a satisfactory environment. Also it should be realized that at certain stages in their life history most organisms are more sensitive to toxicants and require more favourable environmental conditions. The chain of life is no stronger than its weakest component. Further, environmental conditions must be safe or favourable under conditions of continuous exposure. They must be conducive to the survival, growth, reproduction, the general well-being and the production of a crop. Levels or concentrations at which adults may survive for prolonged periods may be entirely unsatisfactory for the survival of the species. Conditions also must be favourable for the food chain organisms if a species is to prosper.

Need and Value of Water Quality Criteria

Carefully formulated and well documented water quality criteria for aquatic life are essential for resolving our water pollution problems. Such criteria will be beneficial in a number of ways. They will define the objectives of a pollution control program. Well-defined objectives will contribute to a more favourable public opinion and will aid in securing public support for control programs. Water quality criteria will indicate concentrations and conditions that cause fish kills, limit growth, interfere with production of a crop, or produce nuisance organisms, and thus will aid in eliminating these conditions. They will provide information to conservationists and other interested groups regarding conditions that must be attained in order to restore and maintain our aquatic resources.

Such criteria will help industry as they will clearly define the conditions that must be met. Industry will be better able to select the best sites for new or expanded facilities

and can make long-term plans for waste treatment. These criteria will indicate allowable concentrations of wastes and minimum or maximum levels safe for short-term, long-term, and continuous exposures, and thus enable industrialists to design adequate waste treatment facilities at the time of construction.

If adequately documented and tested, such criteria probably would be widely accepted by the states. This would lead to more uniform regulations and would prevent industrial developers from using the desire of communities for industrialization to secure concessions in waste treatment at the expense of the aquatic resource. Water quality criteria for aquatic life could be of definite assistance also in the prosecution of pollution cases, as they would provide well documented data on toxic concentrations and levels which are required for the maintenance of the biota. Such data would eliminate arguments as to what is toxic or harmful and would expedite decisions as to whether or not pollution exists. In this manner they would be effective in the restoration or maintenance of the aquatic biota through pollution abatement.

Setting Water Quality Criteria

Many of those who have waste disposal problems feel that it would be desirable to have a list of potential toxicants, such as arsenic, barium, boron, cadmium, chromium, copper, etc., with allowable concentrations for each expressed as p.p.m. Such a waste disposal "cookbook" would have certain advantages. It would be clear-cut and simple, it could be routinely used by inexperienced men with no special knowledge of toxicity problems or the requirements of aquatic life; it would not require a detailed analysis of the problem, and when allowable levels were met those discharging wastes would be absolved from further responsibility. Such an approach however is impracticable for several reasons. Good chemical analytical procedures are not now available for all materials when they are mixed together at extremely small concentrations in water. Many of the analytical procedures which are available are not sensitive enough to detect toxicants at the extremely low levels at which they are toxic; i.e., a few parts per billion or a fraction of a part per billion. Most wastes are complex mixtures of substances and, since toxicities are not always additive, the toxicity of such wastes cannot be determined by simply totalling the toxicity of known components of the waste. Further, there are interactions between the components and there may be synergistic or antagonistic actions. The toxicity of many wastes is significantly influenced by the quality of the receiving water. Among the factors influencing toxicity of a waste are temperature, DO, CO₂, pH, hardness and other materials which are in solution (1). Toxic materials are generally more rapidly toxic at higher temperatures and organisms are less resistant to toxicants at low dissolved oxygen or high CO₂ concentrations (2). The pH of a receiving water can be a governing factor in toxicity. Ammonia wastes can rapidly become more toxic as the pH increases above 8.2 (3). The heavy metals and certain other materials are more toxic at low pH values and are much more toxic in soft water than they are in hard water (4). The toxicity of beryllium and uranium to test fish was found to be 60 to 80 times greater in soft water than in hard water (5). With a nickel cyanide complex a drop in pH value of 1.5 units resulted in more than a thousand-fold increase in toxicity to the test fish (6). For application over wide areas such standards would have to specify levels safe for the most sensitive species, under the water quality conditions that render the waste materials most toxic. Thus, a company discharging copper wastes into a hard water stream would be required to treat the wastes

to the same extent as one on a soft water stream even though the safe level of concentration of the material in the effluent entering the hard water stream might be 25 times that in the soft water stream.

Numerical criteria for application over wide areas should not be set for complex wastes and for those materials whose toxicity is significantly affected by the quality of the receiving water. Criteria for such wastes must be arrived at through a "tailor-made approach"; that is, their toxicity to resident species must be determined at each location. It is hoped that safe levels can be determined through the use of application factors with the results of short-term bioassays which evaluate the effects of water quality on the waste. The application factor for each particular kind of industrial waste would be determined by detailed investigations including long-term bioassays, physiological, histological, histochemical and other studies, to determine levels of the wastes that are safe under conditions of continuous exposure in waters of selected quality. These factors then would be used with TL_m values obtained from short-term bioassays that use for dilution, water taken from the receiving stream at the point at which the wastes are to be added. These tests would be carried out to evaluate the effects of that particular water on the waste under consideration, and they would evaluate most of the effects of the quality of the receiving water. It is hoped that some procedures of this nature can be developed for indicating safe levels of a particular waste in waters of different quality.

It is believed that numerical criteria which will be applicable over wide areas can be set for such environmental factors as DO, temperature, CO_2 , and pH, and for those materials the toxicity of which is not significantly influenced by the quality of the receiving water. The synthetic organic pesticides are important members of this latter group.

Meeting the Present Problem

While considerable data are available on the environmental requirements of aquatic life and the toxicity of certain materials, much remains to be learned. There are many materials and wastes for which we do not know the safe concentrations in different types of waters for either short or long-term exposures. Further, the rate of production of new materials, especially petro-chemicals and synthetic organic materials, is steadily increasing. The determination of the effects of these materials on the aquatic biota is a continuing task which will not be completed in the near future. If we delay until we have all the answers, the setting of water quality criteria will be far in the future and may never be accomplished. It is imperative, therefore, that we use the knowledge we now have to set up tentative criteria that can be modified in the future on the basis of new findings. In this way it may be possible to save much of our aquatic resources that might otherwise be destroyed.

Summary and Conclusions

Water is one of our most important basic resources. It is now generally recognized that our fresh-water supplies are definitely limited, that they cannot be increased effectively by any known economically-feasible method, that water shortages will develop in the future, and that we must reuse our water extensively if our supplies are to meet future demands. Effective reuse of water requires definite knowledge of the quality of water required for each use and adequate water quality criteria to insure such quality. Water quality criteria for the protection of aquatic life are urgently needed since water pollution

is a principal cause of unfavourable environmental conditions in our fresh, marine, and estuarial waters. Pollution control is a necessity and must be given the highest priority if we are to restore, maintain and develop our aquatic resources. The first step in the program is research to determine the environmental conditions which are required for the survival, growth, reproduction, and general well-being of the important members of the aquatic biota. A knowledge of these requirements is basic to the setting of water quality criteria to insure their continued well-being.

In setting water quality criteria it is the extremes of environmental conditions that must be delineated because they determine the survival of an organism and the suitability of an environment. For the production of adequate crops the ranges of most favourable conditions should be defined also. While criteria are needed to indicate safe levels for short exposure periods, stress should be laid on the determination of the levels of conditions which are not harmful under conditions of continuous exposure and which are conducive to the survival of the species. Criteria also are essential for maintaining conditions favourable to the organisms in the food chain.

Water quality criteria based on adequate and carefully formulated data will be of great value in the restoration, protection and production of aquatic resources. Such criteria will define the objectives of pollution control and waste treatment, promote uniform regulations, acquaint the public with the problems and basic aims so that public opinion can be an effective force in pollution abatement, and define pollution so that it can be more readily demonstrated in the courts.

Water is the dominant habitat on earth. It supports a great assemblage of aquatic life that provides a high protein, low fat, rich mineral food on which we may have to depend more and more in the future. Much of our recreation is dependent on aquatic resources. These resources are well worth our best and most earnest efforts for their protection, restoration, and wise use.

A survey of our efforts in the field of water pollution during the past 50 years shows a lack of clear-cut objectives and a well defined plan and demonstrates the need for a better and more effective approach to the problem. In meeting our water resource problems we must be guided by past events, recognize clearly our present needs, and plan effectively for the future.

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The Salmon Fishery in Nova Scotia

by

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Introduction

The Honourable G. I. Smith, Minister under the Water Act, Province of Nova Scotia, has requested the Department of Fisheries of Canada to provide the following information on salmon in Nova Scotia:

(1) A pretty complete historical summary of salmon fishing in the province, both rod and commercial.

(2) List of salmon streams in the province now and their estimated average annual catch for as many years back as the Department can provide.

(3) A list of salmon rivers which in the opinion of the Department have been destroyed or seriously affected as salmon streams by virtue of hydro development and an estimate of the probable effect on both rod and commercial fishing in relation thereto especially the commercial fishing in the estuary.

(4) The effects on the present yield of future reasonable conservation measures and the estimated cost of such measures.

This submission attempts to supply this information as completely as possible.

History of the Commercial Fishing

The first settlers in Nova Scotia found the rivers and streams of the province teeming with salmon. Before their arrival, the Indians utilized the salmon but took only a very small portion of the stock. This abundance of salmon in the rivers was one of the reasons for the settlers locating their village or town sites near the mouth of the rivers. Simeon Perkins relates in his diary that Liverpool was chosen as a town site because of the immense salmon runs in the Mersey River. During these early years, salmon were exploited heavily by the fishermen and shipped by schooner loads to the English market. Later entries in Perkins' diary state that in a short period of time they had depleted these resources and that it was necessary for the fishermen to go as far as the Gulf of St. Lawrence, the west coast of Newfoundland and even Labrador to obtain their boatloads of salmon for the British market. It would appear that the stock was, to all intents, virgin when the white man commenced its exploitation; that he fished off the accumulated stock and continued to the point of real depletion.

Although no records are available for these early days, the industry was revived again after the initial slaughter and provided a fair source of revenue for many fishermen during the late 1700's and the 1800's. Methods of operation included drift nets in off-shore waters, trap nets along the shore and trap and gill nets in the estuary.

The first catch records begin in 1870 after the Department of Fisheries was established, and these commercial catch statistics have been collected every year since that time. Early figures may not be accurate as compared to the ones collected in later years, but they are useful in showing the trend of the catch.

Figure 1 shows the annual commercial landing of salmon in Nova Scotia from 1870 to 1960. Wide fluctuations in the catch have occurred during this period. Sharp increases in the mid 1870's and 1880's were followed by sharp decreases in the early '80's and '90's. After 1890, there was a gradual trend upwards until 1920 when a sharp drop in the catch occurred. The most recent peak occurred in 1930 but since that date the catch has declined steadily and reached a new low in 1955. During the last five years there has been a gradual upward trend, but total landings are still only half the average level of the past 25 years.

There is a close correspondence between fluctuation in commercial landings in all parts of the Canadian Atlantic Coast and on the eastern Atlantic around the British Isles. This fact will be discussed later.

Table I shows the number of traps, gill nets and drift nets licensed from 1929 at 10-year intervals. Before this period there was no breakdown of nets given in the annual reports. According to the licenses issued, the number of gill nets is at the same level as 1929 but the traps have decreased almost 65 per cent from the 1929 figure. Similar decreases may have taken place in the gill net fishery, but this is not indicated by the licenses issued. Many people take out a license to hold their berth but may not fish during the year. Others fish only part time or in the evenings while holding other jobs to make their living.

Table I
Trap and Gill Net Licenses Issued at ten year intervals 1929-1959

Year	Traps	Nets
1929.....	478	693
1939.....	499	1,672
1949.....	376	870
1959.....	178	669

Table II gives the landed value of salmon at 10-year intervals since 1890. With decrease in the landings, the value of the product has increased during the last 30 years, because of the increase in the price of this luxury food.

Table II
Landed Value of Salmon at ten year intervals 1890-1959

Year	Landed Value
1890.....	\$ 92,000
1899.....	94,611
1909.....	91,890
1919.....	69,348
1929.....	125,513
1939.....	76,337
1949.....	124,800
1959.....	111,600

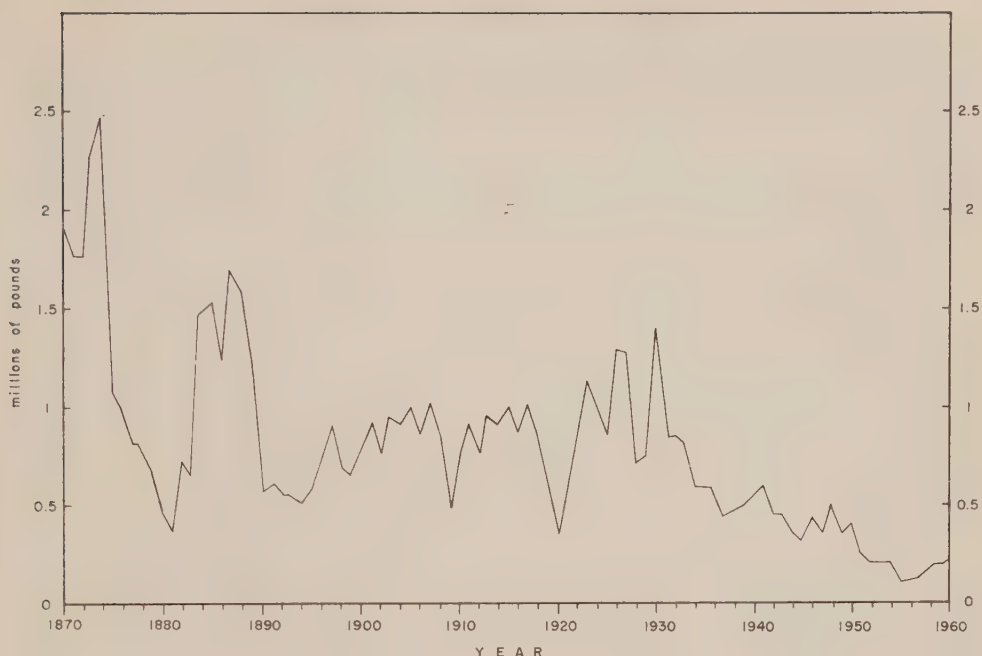


FIGURE 1. Commercial landings of Atlantic salmon in Nova Scotia for 1870-1960.

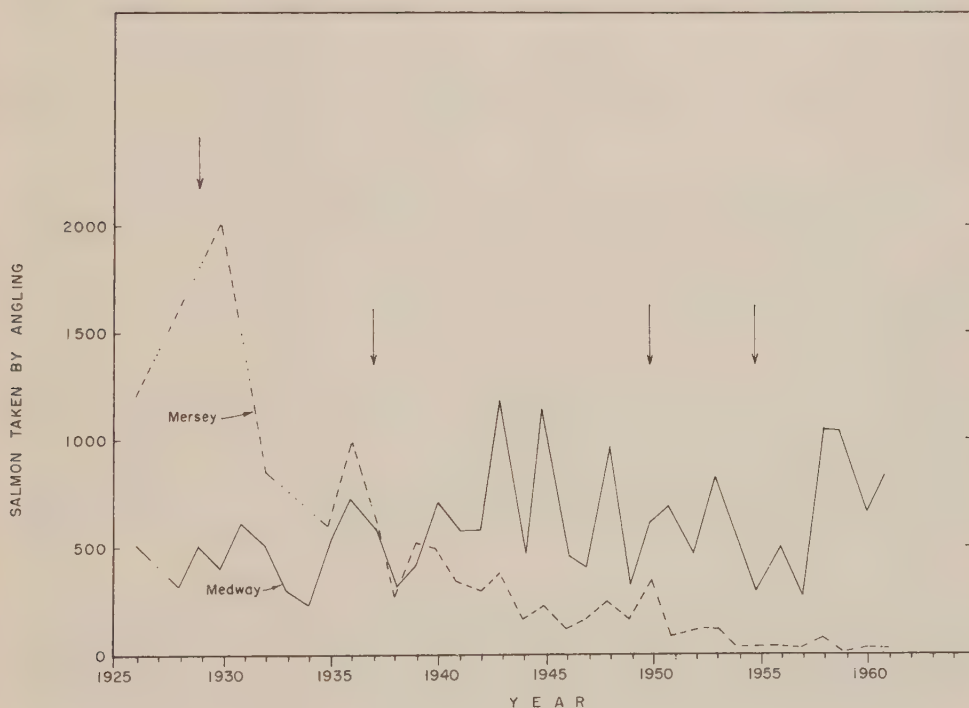


FIGURE 2. Comparison of salmon catch for Medway and Mersey rivers from 1926 to 1961. Arrows indicate the years that hydro dams were constructed on Mersey river. Angling figures not available for years represented by dotted line.

History of Salmon Angling

Commercial landings of the salmon are recorded in the Annual Reports of the Department of Fisheries since 1870 but no official records of angling catches appear before 1923. In fact, official records for many rivers are not recorded until 1935. The reason for this lack of records is that angling was not pursued by very many people before the 1920-30 period. Easier transportation, principally by automobile, along with more leisure time have been the main reasons for the increased interest in the sport in the last 30 years.

No doubt some of the early settlers angled for salmon, but their number would be very small. During the early settlement of the country, the rivers were full of fish and these could be taken easily with spears or nets. Few people had the time or the equipment for salmon angling.

During the 1800's most of the angling was carried out by the Imperial Army officers stationed in Halifax, the British nobility in the province and a few professional sportsmen. These were the people with the money and time to follow the sport. The land around Indian River was bought by the Mason family in 1825 to obtain the fishing rights on the river for the purpose of catering to the garrison officers at Halifax.

Most of the angling was carried out on the rivers within easy travelling distance of Halifax. An 1868 report of Mr. F. H. D. Vieth on salmon angling mentions the excellent salmon angling available on the Ingram, Indian, Nine Mile, Pennant and Sheet Harbour rivers. An 1869 annual report of the Department of Fisheries states that Margaree River, for a number of years, had been a favourite resort for sportsmen from Halifax and other parts of the province. T. R. Pattello's book describes a fishing trip to the Medway River in 1880. He states that the Medway was a famous resort for salmon fishermen and that immense shoals of fish entered it. In another chapter he says that in the early settlement of the country the LaHave River waters teemed with salmon, shad, sea trout and alewives. While fishing the LaHave during this period, he mentions an encounter on the river with army officers from Halifax, who were also angling.

One of the earliest records found describes a fishing trip to Gold River in the year 1842 by four army officers from the Halifax garrison. The article states that the Gold River had only been fished by rod for about nine years, but that some of the Indians who had migrated from Windsor to net and spear the spring run of salmon were turning to fly fishing.

Catch records of salmon anglers of the 1800's are very sketchy. On the 1842 trip to Gold River, the soldiers caught 114 fish during their three-week stay. Vieth reports around 1848 that one man took 19 salmon in one day from the Sackville River and that even the inexperienced angler could catch four or five salmon a day. During the same period, another angler caught 48 salmon on the Musquodoboit in seven days. Pattello reports seeing 50 salmon in the pool below Davidson Mill on the LaHave River in 1886 and mentions catching 19 salmon in one week's fishing on the LaHave.

Very little reference is made to salmon angling in the Department's Annual Reports for the period of 1869 to 1900. Most of the references concern the Margaree and state only that angling was good if water levels were favourable or that fly fishing was poor because of low water flows during the summer months.

At the turn of the century the number of salmon anglers in the province was small. Many of the older guides, when asked about the number of fly fishermen for salmon, stated

that you could count on the fingers of one hand the number of local residents following the sport, and the number of outsiders visiting the streams was also small, with a few exceptions like the Margaree and Medway Rivers. During this period, protection officers had large districts to patrol and their numbers were small, so it was not difficult to obtain salmon with a spear or a net if fish were required. A. P. Silvers, in his book published in 1908, remarked that a bare score of anglers were tempted to salmon fishing in the province. An angler on North River, Victoria County, for 40 to 50 years, stated the people of the area regarded him as a "black sheep" for his salmon angling activities around the turn of the century.

One of the best references found pertaining to the number of salmon fishermen and lease holders in the early 1900's was in a speech given in the Provincial House in 1913 by Mr. Hall during the debate on the free fish legislation. "If we buy out 50 to 60 people having special fishing rights in the province, the great bulk of the people will not have any great benefit. Probably there are only about 100 people in the province who were fitted out and could spare the time and necessary expense to follow the sport. Possibly another 100 men who could go to the LaHave or Margaree and avail themselves of the privilege when the exclusiveness was removed."

With so few anglers following the sport in the early part of the century, leased waters were not a serious problem. Such waters owned by non-residents were generally available to the public except for a few weeks when the lessees arrived to fish. Only in certain sections of the province, especially where the lease owner catered to salmon fishermen, were the waters restricted from the public during all of the fishing season. By 1917, all waters were opened to public fishing.

Among the resident anglers of the early part of the century were a few so-called "commercial anglers". These were residents of the area who angled for salmon and then sold their catch.

Interest in salmon fishing gradually increased during the first quarter of the present century. The annual reports for this period refer to the increasing number of non-residents coming to the province to fish and also the increase in native anglers. Although many were trout fishermen, many of these people turned to salmon fishing as conditions were improved on the salmon rivers by proper fishways and stream clearance. Improvements to the Mersey River around 1920, resulting in large runs of fish upriver, brought many salmon anglers to the area. Many of the local people also took up the sport, and some found that guiding was a way of following their favourite sport which would also provide wages at the same time. Most of the angling was confined to the larger rivers, such as the Mersey, Medway, Margaree and St. Mary's or smaller rivers near the greatest concentration of the population. One annual report for this period states that since many sportsmen frequented the few well-known spots, local over-fishing was the consequence, with many ideal spots seldom visited.

The gradual increase in salmon angling, started in the first quarter of the century, was quickly accelerated during the 1930's. Improved means of transportation accounted for the chief interest in the sport. With the coming of the car, fishermen could reach the distant streams conveniently, and have time to spend fishing. This also meant more angling pressure to the smaller rivers.

During the 1940's, because of the war, the effort dropped off from the sharp increase of the previous decade, chiefly due to lack of transportation and leisure time.

After the war, interest in salmon fishing again picked up and a tremendous increase in effort has taken place during the last ten years. Most of this is attributed to easy means of transportation, more leisure time and the availability of better and cheaper equipment.

Annual Average Catches on Angling Streams

The first official salmon angling figures are recorded in 1923 and are for the Margaree River. Catches for a few of the smaller rivers in Guysborough County are available from the annual reports from 1925 and in some years during the period 1928 to 1935 annual salmon angling figures for the Medway and Mersey Rivers were recorded. The majority of the rivers have no recorded salmon angling catch until 1936 and there are some gaps up to 1949. These earlier figures would not be as accurate as the ones collected after 1949 but the statistics are useful to indicate the trend during this period.

Special effort was made from 1949 on by the Department to improve the collection of salmon angling statistics and the figures for the 1949 to 1961 period represent about 90 per cent of the salmon legally angled. Although records are maintained for 78 streams in the province, less than half of these yield consistent catches of any numbers of salmon over the 13-year period. Only those with an average of 10 or more salmon for the 13-year period are included on the list in this report.

Salmon streams in the province may be divided into two groups: 1) angling streams, and 2) late-run salmon streams.

Angling rivers, yielding an average of 10 or more salmon to the fly fisherman in the last 13 years, are listed in Table III. Column I shows the average catch for the number of years statistics are available. Column II gives the more accurate average catch for the period of 1949-61. The average catch for the province over the last 13 years is about 4000 salmon, and the percentage of the total average catch attributable to each river is listed in column III. The rivers yielding large catch are few and most of the rivers produced less than 100 fish a year to the angler. No figures are available for salmon streams within the boundaries of the Cape Breton Highland National Park.

Although only 34 rivers are listed as angling streams, almost every river in the province has a run of salmon entering it during the fall when water conditions are suitable. Even among the angling rivers, the fall run is larger than early migrations into the streams. In the late-run rivers the angling season is closed by the time these salmon move into the streams. Some of the better late-run rivers in the province providing little or no angling are:

Middle River, Victoria County
Baddeck River, Victoria County
Mabou River, Inverness County
Sutherland River, Pictou County
East River, Pictou County
West River, Pictou County
Wallace River, Cumberland County
River Philip, Cumberland County
Shubenacadie System, Halifax and Colchester Counties

Table III
Average Annual Salmon Catch for Nova Scotia Angling Rivers

River	County	Av. Catch	Years	Av. Catch 1949-61	% of total Av. Catch
Medway.....	Queens	630	35-61	612	15.7
St. Mary's.....	Guys.	465	27-61	531	13.7
LaHave.....	Lun.	431	35-61	404	10.4
Margaree.....	Inv.	425	23-61	317	8.2
Sheet Harbour W.....	Hfx.	222	39-61	279	7.2
Moser.....	Hfx.	170	36-61	197	5.1
North.....	Vic.	159	29-61	132	3.4
Gold.....	Lun.	102	29-61	100	2.5
Port Dufferin.....	Hfx.	78	36-61	99	2.5
Ecum Secum.....	Hfx.	82	27-61	89	2.3
Mersey.....	Queens	243	35-61	82	2.1
Grand.....	Rich.	40	31-61	74	1.9
River Philip.....	Cumb.	138	35-61	71	1.8
Tusket.....	Yar.	87	35-61	71	1.8
Ingram.....	Hfx.	98	36-61	69	1.8
Nictaux.....	Anna.	76	35-61	69	1.8
Annapolis.....	Anna.	95	35-61	63	1.9
Musquodoboit.....	Hfx.	91	36-61	63	1.6
Ship Harbour.....	Hfx.	70	36-61	62	1.6
Liscomb.....	Guys.	59	31-61	62	1.6
Petite.....	Lun.	107	35-61	58	1.5
Round Hill.....	Anna.	61	35-61	57	1.5
Sheet Harbour E.....	Hfx.	48	39-61	54	1.4
Kirby.....	Hfx.	33	38-61	40	1.0
Salmon.....	Digby	44	35-61	39	1.0
Tangier.....	Hfx.	62	36-61	32	0.8
LeQuille.....	Anna.	35	35-61	27	0.7
Gaspereau.....	Kings	28	35-61	25	0.7
Quoddy.....	Hfx.	17	40-61	22	0.6
Middle.....	Lun.	39	35-61	20	0.5
Clyde.....	Shel.	31	35-61	17	0.4
Baddeck.....	Vic.	16	36-61	15	0.4
East.....	Lun.	29	35-61	13	0.3
Gaspereau Br.....	Guys.	13	28-61	11	0.2

Most of the late-run rivers providing little or no angling flow into the Northumberland Strait and Minas Basin areas. Tagging experiments have shown that these small rivers contribute much to the commercial fishery on other sections of the Atlantic Coast. The size of the run entering some of the better late-run streams may be shown by trap records at River Philip where the Department makes a salmon collection every year. These are recorded in Table IV. Only an average of 71 salmon were angled annually in the period 1949-61 on this river.

Figure 3 shows the annual salmon angling catches from 1936 to 1961. The average angling catch in the province over the last 25 years has been about 4000 salmon. The angling statistics, for the short period of time they have been collected, do not show the severe decline experienced by the net fishermen. Many anglers state that the visible stock is less but superior tackle and more persistent fishing have kept them up. In 1930 the catch figures were reported to be falling off, but as no official records are available before this period, no comparison can be made.

Table IV
Number of Salmon Trapped at River Philip During the Fall 1947-1960

Year	No. Trapped	Year	No. Trapped
1947.....	1,175	1954.....	678
1948.....	1,178	1955.....	340
1949.....	828	1956.....	122
1950.....	757	1957.....	213
1951.....	607	1958.....	596
1952.....	97*	1959.....	486
1953.....	669	1960.....	507

*Trap washed out

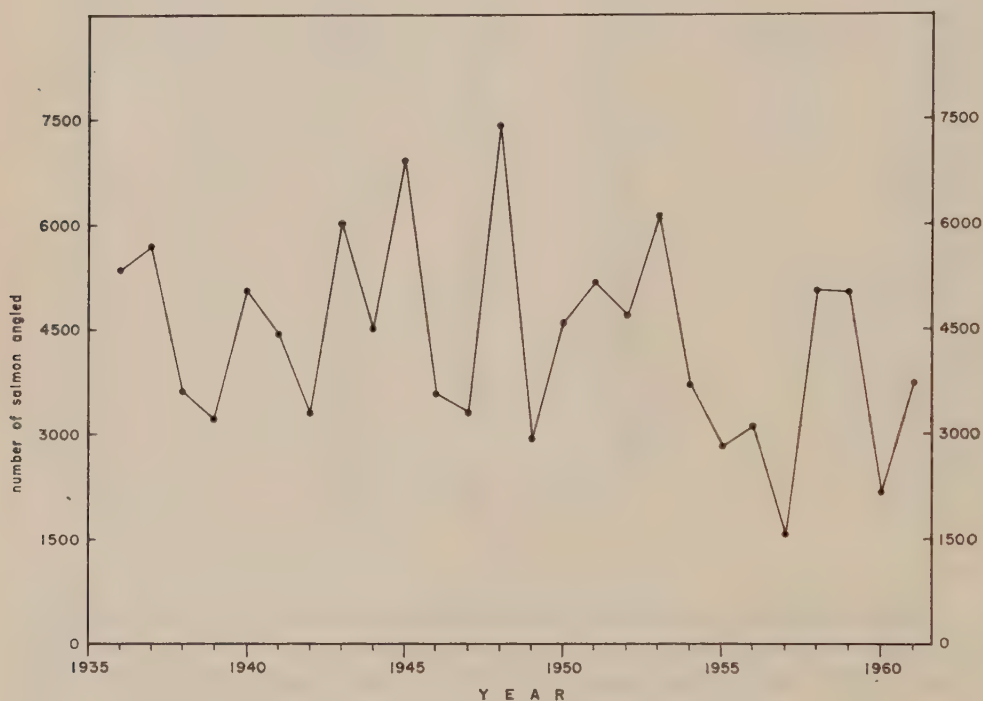


FIGURE 3. Salmon angling catches for Nova Scotia as reported for the period 1936-'61.

Effects of Man-Made Changes on Salmon Environment

The river teeming with salmon as described in the early literature has definitely disappeared since man settled in the province and started to develop its resources. There has been a sharp decline in the commercial fishery and a pronounced decrease in angling if earlier figures are reliable. To understand why development of other natural resources affect the salmon fishery, it is necessary to consider certain facts about the life cycle and population dynamics of the Atlantic salmon. Salmon eggs deposited in the gravel of the river bed during the fall, hatch in the spring. The salmon spends its early life in the river,

runs to sea for its middle years and returns to the river to spawn. During its early years in the river many conditions contribute to the natural mortality. It can be attacked by disease, eaten by predators, killed by pollution, shock, lack of food or high water temperatures and stranded by low water conditions. During its early river life, fishing mortalities are not present. Similarly in the ocean, its numbers are reduced by natural mortality, about which we know too little. Fishing mortalities come into play as it approaches the estuaries on its return spawning migration and this continues in the river. If, in addition, spawning areas are inaccessible or destroyed and rearing areas are diminished, the number of resulting progeny are severely limited. Therefore, any man-made changes in the river environment which reduce or destroy spawning and nursery environment limit the reproductive potential of the fish and of the environment.

Management's aim is to rebuild the stock of salmon to its maximum yield. For several reasons the level of abundance described by Perkins can never again be reached. This early fishery operated on a virgin stock and reduced the population which had to this time been subject only to natural mortality. With this new pressure, the fishery reached a point of maximum sustained yield. This is defined as the largest average catch which can continuously be taken under current environmental conditions. This is a more desirable and stable level than the original high and unsustainable catch. Also, adverse and unknown factors are operating in the sea to depress salmon populations, as shown by similar trends on the eastern and western sides of the Atlantic. Finally, many river environments have been adversely altered irretrievably by man. Although the damage to the rivers is great, it is nevertheless in this area that it can be reduced and prevented, and in many cases proper environmental manipulation can rehabilitate a large portion of the freshwater habitat. Management, therefore, aims at stabilizing the greatest possible favourable river environment for maximum productivity of this fish and to ensure that this is fully considered by those responsible for modern multiple use of rivers.

Much damage can be traced to lumbering and agriculture in the early years and to hydro development in the later years. Pollution from industry also shares in the blame, but to a lesser degree in this province than in other Maritimes areas. Changes in the freshwater environment resulting from lumbering operations and hydro installations will be considered here.

Lumbering

Early settlers found abundant natural resources when they first arrived. As population grew the exploitation of these resources increased. In regard to salmon fisheries, not only the extensive fishing as described by Perkins' diary but other man-made changes directly affected the salmon. As early as 1762, there is mentioned the construction of a dam for mill purposes in the Mersey River and by 1775 the need for regulations regarding the fishery was realized.

Lumbering operations started gradually, but by the 1880's extensive damage had been done to the fishery by their direct action. Mill dams not only caused obstructions to fish entering the spawning streams but destruction of spawning grounds from log driving and dumping of mill wastes. Extensive logging operations changed the environment by removing large blocks of timber, causing quick run-off in the rivers, higher water temperatures in the summer and silting from erosion.

A survey of all rivers in Nova Scotia was carried out by F. H. D. Vieth in 1881 and 1882. According to his report, almost every river, stream and tributary in the province had one and, in many cases, several dams obstructing the passage of anadromous fish. On River Philip, 17 dams were found. On most of the rivers, no fishways or fish passes were installed, or if installed, they were not considered efficient to pass salmon. The only exceptions on the mainland of Nova Scotia were the Mersey and Medway with good fishways, a portion of the St. Mary's, and several smaller rivers such as Nine Mile and Pennant unobstructed. Heavy freshet conditions on Cape Breton Island prevented construction of dams on the large rivers, but all the tributary brooks to these rivers were obstructed with dams. Special mention was made of the mills dumping sawdust and other waste products into the river and ruining spawning areas below the dams.

Some improvements were made in the fishways after his inspection, especially on the LaHave, Sackville and Annapolis Rivers.

The 1890 Annual Report of the Department of Fisheries states that of the 27 salmon rivers on the Northumberland Strait, only four were unobstructed by mill dams. None of the obstructed ones were provided with fishways. In the same year, Inspector Hockins, reporting for the eastern mainland, stated that 90 per cent of the fishways in his district were not in such a condition as to allow fish to pass.

From these reports, it would appear that the salmon should have been wiped out by 1900. Although these mill dams and driving dams had an adverse effect on the salmon, most of them, because of their size and method of operation, allowed salmon access to the river during certain times of the year. Many were low dams with spillway or sluice gates and they impounded very little water. Operations were confined to a few months and then the gates were opened, or because of their low head, water flowed over them during any freshet period. Thus, salmon were not completely obstructed from their spawning grounds.

Early reports indicate that salmon entered the rivers in March or even February. These dams may have caused the loss of these very early-run fish. Of course, quick run-off in rivers from lumbering operations is still found today.

Effects of Hydro Development on Salmon Streams

Following the decline of lumbering operations, hydro installation began on some of the salmon rivers. These dams had a more serious and lasting effect on the salmon's fresh-water environment. These were high dams, permanent structures, many provided large storage areas, and their method of operation is quite different. It would be well to cover in broad terms the general problems which arise when hydro installations are made on salmon rivers to show their direct and indirect effects on salmon as outlined by Brett.

(1) Reduced or no flow on weekend or low water periods not only delays entrance of fish into the river but may make them more vulnerable to the predator, poachers and fishermen. Quick draw-down not only affects salmon nursery below these installations by reducing its size but may damage spawning redds during winter months when eggs are deposited in the gravel.

(2) No matter how efficiently a fishway is built there is still the question of whether salmon will find and enter the ladder and do so without delay, fatigue or loss of energy from attempting to fight the spillway or draft tube waters.

(3) River conditions above the dam are altered so that typical nursery and spawning areas (shallow riffle water over cobble bottom) may be wiped out by flowage area.

(4) Downstream migrants suffer severe losses if they use the turbine exits on their seaward journey.

(5) In diversion type installations on small streams sufficient water is never available to make proper use of the old stream bed, and in this case, the river is virtually destroyed for salmon.

After reviewing the above list, it can be seen that any salmon river is directly or indirectly affected by hydro development, some more seriously than others. The degree of damage is related to (1) the position of dams, whether in the headwaters or estuaries; (2) provision of fishways; (3) extent of headponds.

The Mersey River is the best example to cite regarding the effects of hydro on salmon rivers, because angling statistics are available before hydro construction was started. This river was rehabilitated in the early 1920's by construction of efficient fishways in the existing dams and by heavy stocking. It reached its peak of production around 1930, yielding about 2000 salmon to the anglers in that year. Medway catch in the same period was about 500 salmon. In 1929 hydro installations were made on the headwater areas of the Mersey, followed by other installations in 1937, 1950 and 1955. The catch for both Medway and Mersey for 1926 to 1961 is shown in graphical form in Figure 2. Two to four years after each installation on the Mersey, a decline in salmon catch is observed, until the present catch is only about 25 fish a year. Medway River, located in the same area, has maintained an average of almost 600 per year during the same period. Hydro installation on the Medway is located nearer the headwater and has not adversely affected the lower part of the river, although counts of salmon through the fishway at this installation for the period of 1954 to 1958 show a drop of from 16 in 1954 to only one in 1958.

A similar decline in salmon angling catch cannot be shown for East River, Sheet Harbour, because hydro installations were made before angling statistics were collected, but veteran anglers in the area claim that the river, in angling yield, was similar to or better than the Medway or St. Mary's Rivers. A recent biological examination of the potential of its unused water from which salmon are barred tends to confirm this. Today it produces about a tenth of the yield of the Medway or St. Mary's.

Rivers with diversion dams, such as Indian River, are completely ruined for salmon. Nictaux has produced no fish to the angler in the last two years compared to an average of over 100 per year in the 1949 to 1954 period. Similar conditions will exist on the LeQuille River when diversion work is completed.

Therefore, salmon rivers that have been destroyed or seriously affected by hydro development are listed below:

Mersey River
East River, Sheet Harbour
Indian River
Nictaux River
LeQuille River

Other salmon rivers affected to a lesser degree by hydro include:

<i>Ingram River</i>	<i>Tusket River</i>
<i>Petite Riviere</i>	<i>East River, Chester</i>
<i>Gaspereau River</i>	<i>Liscomb River</i>

On this second group of rivers, salmon angling catches, where records are available, show definite declines since hydro installation. Liscomb River has been included in this group because earlier reports indicated that before the dam was constructed at the falls, salmon could surmount the falls at certain water levels.

With the tremendous increase in salmon angling pressure during the last ten years, the loss of several rivers is a serious blow to the sport fishery. This results in an increase of fishing pressure on the remaining streams. The number of rod days on the Medway has increased from 1020 in 1949 to 8486 in 1960, while the Mersey has dropped from 730 to 560* during the same period. With the loss of the one stream, the pressure is changed to another.

Because of the complex behaviour of salmon, the effects of hydro development on the coastal commercial fishery are not confined to a single area but are spread over the whole Maritime fishery. Tagging and marking experiments have shown that fish marked as smolt on the Pollett River, tributary to the Bay of Fundy, are taken in important quantities by commercial fishermen in trap nets around Newfoundland and in the drift nets of the Miramichi area. Similarly, many fish originating on the Miramichi are taken around the east coast of Newfoundland and by other commercial nets in the Maritimes.

The effects of hydro development on estuarial fishing are difficult to ascertain because of the habits of returning fish. Experiments have shown: (1) that salmon have a strong homing tendency to the stream of their origin but (2) may wander in and out of other estuaries and be subject to capture in the process. One effect, therefore, masks the other. There can, however, be no doubt that a hydro development which reduces the number of fish running to sea also reduces the number returning and has an influence on overall catch. In some cases the effect appears to be felt locally. For instance, net fishermen interviewed in Petite Riviere claim they averaged 25 salmon per net before hydro installation in 1939 and now they are lucky to take five a year.

Present and Future Management Procedures

Management consists of two types of procedures, both leading to the same end: (1) regulation of the fishery to ensure that enough spawners, and no more, reach the spawning grounds; (2) manipulation of the fish populations and their environment to ensure that the river produces the maximum number of which it is capable. In the present state of salmon stocks regulation usually means limitation, but if the stock became overabundant, regulation could just as legitimately encourage greater exploitation. Manipulation of the environment involves resisting, and sometimes reversing, the man-made destructive influences on the environment followed by actual stream improvement. Manipulation of the stock involves control of the numbers of fish themselves, either by controlling predation or by actual additions of fish where the spawning potential is less than the nursery or carrying potential.

One phase of environmental manipulation includes projects designed to allow salmon to reach existing spawning grounds or to open up new ones. Such projects range from removal of minor stream obstructions to the building of fishways around natural barriers, with intermediate jobs involving removal of rock obstructions and debris jams, bulldozing channels to confine streams during low flow periods and clearing spawning grounds.

*Successful brown trout introductions in the last five years have, in part, helped to maintain angling interest on the lower system.

A second phase of environmental manipulation, requiring investigation in the near future, involves changing existing river conditions. Shortage of spawning areas could be overcome by addition of suitable gravel to the river bed. Improvement of rearing areas could be accomplished by: (1) adequate water storage for release during low flow periods to overcome the effects of quick run off caused by deforestation; (2) increasing shade and shelter requirements by planting shade trees along the river banks and additions of rocks to the stream.

Supplementing present stocks is carried out by hatchery plantings. These plantings may be used to augment production where spawning has reached a low level, rehabilitate areas where pollution has reduced the number of parr and establish runs in areas inaccessible to salmon. Planting of large fish (smolt size) yields to better survival as it reduces the chances of predators or other factors limiting parr production during its freshwater life. Stocks of hatchery fish are also used for experimental planting and tagging so that more information can be gained to make the best use of the fishery.

A second method of supplementing present stocks now under investigation is the control of mergansers, to increase smolt production. On experimental streams, removal of mergansers during the open water period for a number of years gave an increase in average smolt production of four to seven times the unprotected output. Experimental control has been carried out on the St. Mary's River for a number of years, but expected increases did not materialize because the effect was not concentrated during all of the open water season. More investigation of this technique is planned for the Margaree River.

No two rivers are alike and no formulae can answer every need. Each river requires its own study to assert what procedures are necessary to improve it. Therefore, each river requires a survey by a biologist to estimate nursery and spawning production, locate polluted areas and obstructions, and engineering surveys are required for fishway studies around natural barriers and dams.

Expected Yield and Cost of Management Procedures

Before considering the cost of management procedures and expected yield, it would be well to set a value on both a salmon caught commercially and on a salmon angled. The market value of the fish flesh is only one component of a complex evaluation. The value of the gear is involved in both cases. In the case of angling, it involves guides' services, outfitters' fees, club expenses, transportation costs, along with the intangible recreational and aesthetic value. A survey on the economics of Atlantic salmon in Quebec considered all sources of revenue involved in the angling fishery and arrived at a value of \$158 apiece for angled salmon. Relying only on guides' services and gear value, a more conservative estimate of \$25 apiece can be assigned in this province and this is undoubtedly low. For salmon caught commercially, an approximate retail market value of \$10 apiece for the fish itself can be used.

Cost of management procedures for stream improvement is variable, depending on the size and location of obstruction and type of procedure involved. Removal of small obstructions ranges from \$25 to \$100; bulldozing channels may vary from \$100 to \$1,000; construction of a fishway around a natural barrier may run as high as \$50,000. Similarly, expected yield for such procedures would depend upon the additional amount of spawning and rearing area made available.

Some idea of costs and expected yield may best be shown by citing an example where both environment manipulation and stock addition are required to increase the salmon production of the stream. Liscomb River has a natural falls located about one mile from the estuary. This falls was passable to salmon only at certain water levels. Construction of a hydro dam on top of the falls created a complete barrier to salmon. Stocking of the barren area of river above the falls to build up a run and construction of a fishway at the falls for the returning fish to reach the spawning areas is required. Initial stocking of 60,000 yearling salmon for three successive years would cost \$27,000. Fishway construction was estimated to be \$32,000. A biological survey of the area above the falls showed that adequate spawning areas were available and that the potential rearing area was capable of producing approximately 45,000 salmon smolts. If the adverse effects of hydro installation were not considered, the return from such smolt production should yield 200 salmon to the anglers and 600 to the commercial nets. Angled fish would be taken in their river of origin, but the commercial catch might be removed on other sections of the Atlantic coast. For a total expenditure of \$59,000, the dollar value of the increased salmon yield would be \$11,000 a year. Similarly, costs can be shown for predatory control procedures. Although only experimental at present, a proposed five-year merganser control program on the Margaree River, at a cost of \$66,000, is expected to double the present average angling take of 350 salmon. This is a conservative estimate in the light of results on Pollett River, N.B. The dollar value of the increased yield would be \$8,750 a year, plus the increase in the commercial fishery.

If only the dollar value of the product is considered, the cost benefits may not be favourable in some management procedures but the intangible recreational and aesthetic value must also be taken into consideration. The demand for this type of recreation has increased tremendously in the last ten years, and will continue to increase in the future, as shown by Clawson's estimates of a ten-fold increase in demand for outdoor recreation before the end of the century.

Finally, it should be pointed out that in Nova Scotia management of the salmon fishery is a federal responsibility and all costs and expenditures for this management are paid by the federal government. On the other hand, much of the benefit derived from the salmon resource as a tourist attraction, as a recreational outlet and as a fishery are of immediate concern to the province.

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